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MONOGRAPH OF THE EFFECTIVENESS AND COST OF WATER TREATMENT PROCESSES FOR THE REMOVAL OF SPECIFIC CONTAMINANTS.

VOLUME I. TECHNICAL MANUAL

DAVID VOLKERT AND ASSOCIATES

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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Volume I
Technical Manual

by

Environmental Planning and Engineering
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David Volkert & Associates
4701 Sangamore Road
Bethesda, Maryland 20016

for the

OFFICE OF
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WATER SUPPLY BRANCH

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

This monograph provides information on treatment processes for potable water supplies and their costs. It is intended as a general planning document, giving the user general concepts on what treatment methods are available to remove specific contaminants or reduce them below the limits required or recommended by the 1974 Federal Drinking Water Standards and Guidelines. These contaminants may be physical, biological, radiological, or chemical. General cost estimates for the removal or reduction of contaminant levels can be made by using the cost estimation curves and procedures outlined in the monograph. Volume II of the monograph is a KWIK INDEX which provides additional references for more detailed information on treatments and costs.

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SECTION I

INTRODUCTION

This monograph was prepared under contract to the Environmental Protection Agency, and is a compilation of cost and technical data for water treatment and other techniques which, when applied, will result in the production of water whose constituent limits conform to applicable Federal standards.

The monograph includes capital cost analyses and operating cost data, and is arranged for ready cross reference between contaminant to be controlled and control method. This document should be of assistance to utilities and engineering consultants in making preliminary plans and cost estimates for improved water supply facilities.

Listed below are the proposed revised 1974 Federal Drinking Water Standards and Guidelines(1) compared to the 1962 U.S. Public Health Drinking Water Standards. The proposed standards are used in subsequent sections of the monograph for calculations of process cost effectiveness.

Constituent	1962 Standards	1974 Revised Standards
Bacteria	See appendix A	500 /ml
Coliform Bacteria	See appendix A	See appendix A
Color	15 color units	15 color units
Odor (Threshold)	3 T.O.N.	3 T.O.N.
Turbidity	5 units	1 unit
Arsenic	0.05 mg/l	0.1 mg/l
Barium	1.0 mg/l	1.0 mg/l
Cadmium	0.01 mg/l	0.01 mg/l
CCE	0.2 mg/l	0.7 mg/l(2)
Chloride	250 mg/l	250 mg/l
Chromium (Hexavalent)	0.05 mg/l	0.05 mg/l
Copper	1.0 mg/l	1.0 mg/l
Cyanide	0.2 mg/l	0.2 mg/l
Fluoride - Annual average of maximum daily air temperatures (°C) based on temp. data obtained for a minimum of 5 years		
10.0 - 12.1	2.4 mg/l(3)	1.8 mg/l
12.2 - 14.6	2.2 mg/l	1.7 mg/l
14.7 - 17.6	2.0 mg/l	1.5 mg/l
17.7 - 21.4	1.8 mg/l	1.4 mg/l
21.5 - 26.2	1.6 mg/l	1.2 mg/l
26.3 - 32.5	1.4 mg/l	1.1 mg/l

Constituent	1962 Standards	1974 Revised Standards
Foaming Agents	0.5 mg/l	0.5 mg/l (As Methylene-Blue Active Substances)
Iron	0.3 mg/l	0.3 mg/l
Lead	0.05 mg/l	0.05 mg/l
Manganese	0.05 mg/l	0.05 mg/l
Mercury	-	0.002 mg/l
Nitrate	45 mg/l(as NO_3)	10 mg/l (as N)
Selenium	0.01 mg/l	0.01 mg/l
Silver	0.05 mg/l	0.05 mg/l
Sodium(4)	-	-
Sulphate	250 mg/l	250 mg/l
Zinc	5 mg/l	5 mg/l
Gross Alpha (Including Radium 226)	-	15 pCi/liter
Radium and/or Radium 228	-	5 pCi/liter
Radium 226	3 pCi/liter	-
Gross Beta	1000 pCi/liter	
Beta Particle and photon activity from artificial radionuclides (5)	-	-
Strontium 90(6)	10 pCi/liter	8 pCi/liter
Iodine 129 and/or Iodine 131(6)	-	2 pCi/liter
Tritium(6)	-	8 x 10^4 liter
Aldrin	-	0.00014 μg/l
Chlordane	-	3 μg/l
DDT	-	50 μg/l
Dieldrin	-	0.00014 μg/l
Endrin	-	0.2 μg/l
Heptachlor epoxide	-	0.1 μg/l
Lindane	-	5 μg/l
Methoxychlor	-	100 μg/l
Toxaphene	-	5 μg/l
Organophosphate Insecticides	-	0.1 mg/l (parathion equiv.)(7)
2, 4-D	-	0.1 mg/l
2, 4, 5,-TP	-	0.03 mg/l

(1) Currently under internal review by EPA.

(2) Concentration limit increase due to improved sampling and extraction technique rather than change in standard.

(3) Rejection of supply is at 2 x limit.

(4) No recommended standards for sodium. Treatment methods are included in the manual. See Appendix B page 305 for discussion.

(5) Aggregate dose limit for any water supply system shall not exceed 1500 man-rem/yr. In no case, however, shall concentration produce in any individual a yearly dose to the total body or any internal organ greater than 0.015 rem/yr.

(6) The limits apply when each radionuclide is the only one in the water. When there is a mixture of two or more, the man-rem limits of note (5) apply.

(7) Approval Limit (Health) 0.1 mg of parathion per liter, or the equivalent concentration of organophosphate insecticides based on total organic phosphorus, as determined by suitable chemical or physicochemical method(s).

Provided the total concentration of organophosphate insecticides exceeds 0.1 mg/l as parathion then an analytical gas liquid chromatographic procedure should be employed to determine specific organophosphate insecticides that are likely to occur in water supplies.

SECTION II

PHYSICAL AND CHEMICAL DATA ON THE CONTAMINANTS WITH TREATMENT METHODS

The maximum concentrations listed in this section are those concentrations of the contaminants in the untreated water that can effectively be reduced to acceptable 1974 Federal Drinking Water Standards and Guidelines in a single pass through the process. The percentage of contaminant removed by each process is an indication of the process effectiveness or efficiency in removing the contaminant of interest. Application of the percentage of contaminant removal to the 1974 Drinking Water Standards and Guidelines limits to determine the maximum concentrations (or vice versa) should not be done for the following reasons:

1) Some processes are uniformly effective over a range of contaminant concentration levels, but reach a maximum concentration limit where they are no longer effective, which does not correspond to the maximum concentration limit calculated above. For example, a process may remove 90% of contaminant A up to levels of 1 mg/l in the untreated water. Regardless of further increases in contaminant A levels, the process will remove only 1 mg/l. In effect, the efficiency will drop when the untreated water levels exceed 1.0 mg/l.

2) When a range of values for percentage removal or maximum concentrations are given, then the effectiveness of the treatment process is dependent on factors such as pH level, particle size, saturation levels, water temperature, contaminant levels, overall water chemistry, etc. The reader's judgement must be used to select values for analysis based on prior experience and knowledge of the local water supply under consideration. Detailed data would have to be determined by laboratory analysis or pilot studies.

3) The percentage removal varies with contaminant concentration.

4) Maximum concentrations are unreasonably high if percentage removal is very high (say 99 or 99.9%).

BACTERIA

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 500/ml.

Bacteria in water sources are primarily a result of organic waste pollution. Sources of this waste include decaying vegetative matter, decaying animal wastes, effluent from food processing plants, untreated sewage and others. In addition to direct contamination, bacteria may be transported to open water bodies by air dispersion, birds, and other animals, including man.

Except in cases involving heavy percolation of high bacterial count waters and accidental well contamination, bacteria are a surface water problem.

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Treatment Methods[1]

(1) Chlorination (Pg. 161, 228, 239)
Bacterial destruction approximates 99%
Maximum concentration in feed-water = 50,000/ml.

(2) Ozonation (Pg. 168, 173, 228, 239)
Bacterial destruction approximates 99% (Ref. No. 8, 26)
Maximum concentration in feed-water = 50,000/ml.

(3) Reverse Osmosis (Pg. 119, 227, 235)
Removal efficiency approximates 99%+ when the membrane consists of material which is safe from bacterial destruction.
Maximum concentration in feed-water = 50,000/ml.

The following treatment methods do not provide bacterial reduction sufficient to meet public health standards. Maximum concentration in feed-water varies and is dependent on local conditions. Laboratory analysis required to determine this level. However, their use prior to disinfection may significantly lower treatment costs.

(4) Plain Sedimentation (Pg. 75, 226, 231)
Removal efficiencies range from 0 - 90%+

(5) Coagulation (Pg. 82, 193, 232)
Coagulation may remove significant amounts of bacteria which have become attached to or encapsulated by suspended or colloidal matter.

(6) Rapid Sand Filtration (Pg. 95, 226, 227, 234)
Removal efficiencies range from 0 - 99%

(7) Slow Sand Filtration (Pg. 96, 227, 234)
Removal efficiency ranges from 85-99%

(8) Diatomite Filtration (Pg. 96, 227, 234)
Removal efficiency ranges from 85 - 90%

(9) Microscreening (Pg. 114, 227, 235)
Removal efficiency ranges from 50 - 80%

---

[1] Throughout this section, treatment methods which require a maximum concentration of the contaminant in the feed-water refers to a single pass operation.

ODOR

1974 Drinking Water Standards and Guidelines - Approval Limit (Esthetic) - 3 Threshold Odor Number

Undesirable odors in water are caused by the vapors from many chemicals including halogens, sulfides, ammonia, turpentine, phenols and cresols, picrates, various hydrocarbons and unsaturated organic compounds, some of which have not yet been identified. Frequently it is difficult to determine the exact cause of an odor problem, as many substances have the same effect and mixtures of several substances may be involved.

Possible sources of Contamination

Natural waters may obtain odor producing compounds from living organic substances and decaying vegetation, including weeds, bacteria, fungi, actinomycetes, algae and decaying animal matter. Sewage and industrial wastes may also contribute high levels of odorous compounds. Some inorganic substances such as metal ions in concentrations impart taste and odor to water when their concentrations are sufficiently high.

Treatment Methods

The following processes have been found to effectively remove varying amounts of odor-producing compounds from water. Laboratory tests on raw water samples will be necessary to determine the removal effectiveness of the various processes.

(1) Aeration (Ref. No. 5) [1/] (Pg. 71, 225, 231)

(2) Activated Carbon (Ref. No. 45) (Pg. 175, 239)

The processes listed below are utilized primarily for disinfection. However, they will also remove odor producing compounds in many cases. In all cases where these processes are being used for dual purposes, care must be taken to insure that the odor removal does not interfere with the disinfection capability of the process.

(3) Ozonation (Pg. 168, 239)

Ozone is highly effective for odor reduction. However, the presence of some organic compounds may result in undesirable tastes accompanying its use. Therefore, a two-stage treatment with activated carbon to remove the organics, followed by the ozonation may be necessary for total odor removal.

1/ See Vol. II, KWIK Index, Reference Section, No. 00005.

(4) Superchlorination (Pg. 161, 239)

Superchlorination followed by excess chlorine removal has been found effective for odor removal. The presence of phenols and subsequent formation of chlorophenols may necessitate the use of activated carbon to remove the undesired organics. The efficiency of this operation is variable and requires preliminary testing to determine its effectiveness.

(5) Chlorine dioxide* (Ref. No. 105) (Pg. 180, Table MT-1)

Chlorine dioxide has been used sucessfully in destroying chlorophenols and other odorous substances. Its use in water treatment has arisen largely from the fact that offensive chlorophenols are formed when phenol-bearing waters are treated with chlorine. Chlorine dioxide is more chemically active than chlorine and oxidizes odorous substances at a higher rate. Little is known on the potential long term physiological effects of chlorinated organic compounds present in waters treated with chlorine and chlorine dioxide. For precisely this reason it is suggested that chlorine dioxide treatment be followed by adsorption on carbon to remove chlorinated organic compounds. Usually, however, chlorine dioxide is applied to the finished water, where no subsequent removal of organics is necessary. The efficiency of this operation is variable and requires preliminary testing to determine its effectiveness.

(6) Potassium permanganate (Ref. No. 45) (Pg. 180, Table MT1)

Potassium permanganate has been found to be an effective and economical means of solving taste and odor problems. It has been used successfully for odor control in many treatment plants throughout the United States and in approximately fourteen foreign countries with excellent results reported often with dosages as low as 0.3 mg/liter. The efficiency of this operation is variable and requires preliminary testing to determine its effectiveness.

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*Note:
Regardless of the process used, sufficient amounts of chlorine must be available to ensure complete oxidation, otherwise, intermediate chlorinated compounds may intensify existing tastes and odors.

COLOR

1974 Drinking Water Standards and Guidelines - Approval Limit (Esthetic)-
15 color units

Color in water may be of natural mineral or vegetable origin, as well as a result of industrial or domestic wastes. Natural iron and manganese compounds are examples of minerals which can impart undesirable colors to water. Organic materials such as humus, tannins, peat, algae, weeds and protozoa are examples of natural organics which contribute color to water in the form of complex organic compounds. Irrigation return flows are a major source of color from natural sources in some parts of the United States.

Industries generating colored effluents are too numerous to list fully, however, some of the important color producing processes are mining, refining, explosives production, pulp and paper manufacture, and chemical production.

Treatment Methods

Treatment methods for the removal of color are listed below. Due to the varied nature of color in water, removal efficiencies must be determined by pilot studies for individual cases.

(1) Coagulation (Ref. No. 138) (Pg. 82, 193, 232)

Coagulation is highly successful and widely used for color removal and, in general, the optimum removal increases with increased coagulant dosage. The best removal is usually achieved within a pH range of 4-6. However, since this range is not the optimum pH for minimum solubility of the coagulant, the pH should be adjusted to greater than 6 prior to filtration. Removal efficiency is 95%. Maximum concentration in feed-water = 300 color units.

(2) Slow Sand Filtration (Pg. 96, 227, 234) with Diatomite Filtration (Pg. 96, 227, 234). Removal efficiency is 50-95%. Maximum concentration in feed-water is 30-300 color units, depending on source.

(3) Reverse Osmosis (Pg. 119, 227, 235)

R.O. provides 99% removal for all color producing materials with molecular weights greater than 200. Maximum concentration in feed-water must not exceed 1500 color units.

(4) Ion Exchange (Pg. 150, 228, 238)

Resins have been developed which will remove organic dye wastes, humates and ligates. Removal efficiency is 100%.

(5) Activated Carbon (Pg. 175)

Activated Carbon is highly efficient for removing non-colloidal, soluble, aromatic structured color sources. Removal efficiency is 100%.

TURBIDITY

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 1 unit

Turbidity in water is a result of suspended and colloidal matter from a variety of possible sources. It may be caused by micro-organisms or organic detritus; mineral substances including zinc, iron and manganese compounds; clay or silt and other products of natural erosion; domestic sewage or wastes from various industries, e.g., mining, dredging, logging, pulp and paper manufacturing; and others.

Treatment Methods

The treatment methods listed below have been found effective for turbidity reduction. Efficiencies will vary with the amount of solids present in the raw water source. In many cases, maximum removal efficiency is obtained by utilizing various combinations of the methods listed below, e.g., plain sedimentation, coagulation with sedimentation, rapid sand filtration.

(1) Plain Sedimentation (Pg. 75, 226, 231)
Removal efficiency is 50 - 95%. Maximum concentration in feed-water is 20 JTU (Jackson Turbidity Unit).

(2) Coagulation with Sedimentation (Pg. 89, 226, 233)
Removal efficiency is 80 - 99%. Maximum concentration in feed-water is 100 JTU.

The following treatment methods are efficient for water containing turbidity of 10 JTU or less.

(3) Coagulation without Sedimentation (Pg. 82, 192, 232)
Removal efficiency is 80 - 99%. Maximum concentration in feed-water 5 - 100 JTU.

(4) Rapid Sand Filtration (Ref. No. 18) (Pg. 95, 226, 227, 234)
Removal efficiency is 80 - 99%. Maximum concentration in feed water is 5 - 100 JTU.

(5) Slow Sand Filtration (Pg. 96, 227, 234)
Removal efficiency is 80 - 99%. Maximum concentration in feed-water is 5 - 100 JTU.

(6) Diatomite Filtration (Pg. 96, 227, 234)
Removal efficiency is 80 - 99%. Maximum concentration in feed-water is 5 - 100 JTU.

(7) Microscreening (Ref. No. 132) (Pg. 114, 227, 235)
Removal efficiency is 50 - 80%. Maximum concentration in feed-water is 2 - 5 JTU.

ARSENIC (As)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) 0.1 mg/l.

Possible Sources of Contamination

Arsenic or its compounds is used in many manufacturing processes, including pyrotechny, tanning, dye manufacture and lead shot manufacture. The major use of arsenic has been in pesticides and as a wood preservative. The related compounds are Paris green $3 Cu (AsO_2 \bullet Cu (C_2H_3O_2)_2$, calcium arsenate and lead arsenate.

High concentrations of arsenic compounds have been found to occur naturally in some waters of the Western United States.

Treatment Methods

(1) Coagulation (Pg. 82, 193, 232)

(a) Ferric Chloride ($FeCl_3$) as coagulant
Removal efficiency is 90-99% and maximum concentration in feed-water is 1 mg/l with preoxidation, followed by coagulation with $FeCl_3$ and filtration. Removal efficiency is 99% and maximum concentration in feed-water is 10 mg/l with $FeCl_3$ coagulation, chlorination, and filtration.

If water containing arsenic is oxidized, coagulated with ferric chloride, and then filtered, removal efficiencies of more than 99% can be achieved.

Table AS-1. Efficiency for Arsenic removal in a 150 m^3/day treatment plant using $FeCl_3$ - Chlorine - Filtration methods.[1]

Quantity	Day 1	Day 44	Day 61	Day 88	Day 105	Day 120
Filter rate-m^3/m^2/day		8.7	4.5	4.3	11.0	8.4
Dosage of $FeCl_3$-mg/l	56.5	55.8	30	35.3	32.8	30
Dosage of Cl_2-mg/l	37.2	25.2	13.5	12.9	9.7	11.3
Residual Cl in finished water-mg/l	2.0	2.1	1.7	0.5	0.1	0.2
pH of finished water	8.0	8.0	8.1	7.8	7.9	8.3
Fe-mg/l						
In raw water	2.0	0.5	0.7	0.4	0.5	0.5
In finished water	0	0		0	0	0
As-mg/l						
In raw water	0.56	0.45	0.56	0.43	0.36	0.42
In finished water	0	0	trace	0	trace	trace
Removed-%	100	100	100	100	100	100

[1] Reference - Y.S. Shen "Study of Arsenic Removal From Drinking Water," Jour. AWWA 65:8; 543 (August 1973).

The filter media used at the test plant was sand which can be regenerated with NaOH solution and arsenic free water rinse.

b. Ferric Oxide $Fe_2(SO_4)_3$ as a coagulant

Table AS-3. Removal of Arsenic (V) Adsorption on Hydrous Ferric Oxide[1]

Initial pH	Dosage of $Fe_2(SO_4)_3 \cdot 3H_2O$ mg/l	Arsenic Removal-per cent			
		Lost to Glassware (Control)	Lost to Glassware and Filter	Coagulation and Sedimentation	Coagulation Sedimentation, and Filtration
5.0	10	5.39	8.68	66	96.5
	20	0.125	4.86	87.7	96.9
	30	7.25	9.4	90.5	96.4
	40	0.119	3.02	91	95.2
	50	3.86	10.6	96.8	99
6.0	10	0.145	4.64	66.2	87.1
	20	0.73	5.88	81.8	97.5
	30	0.32	1.48	91.3	98.3
	40	0.394	3.58	95	99.6
	50	3.02	6.3	96	98.4
7.5	10	0.544	4.16	74.6	94
	20	0	4.41	78.5	97
	30	1.13	2.98	94.5	96.5
	40	4.54	8.6	91.5	99.9
	50	0.408	2.78	96.5	97.5
8.0	10	0.147	1.93	63	88.6
	20	0.427	3.66	65	89.5
	30	3.82	4.42	93	96.5
	40	0.62	7.46	93	96.3
	50	4.35	7.56	95.4	96.5

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[1] Gulledge, J. & O'Connor, J. "Removal of Arsenic (V) from Water on Aluminum and Ferric Hydroxides", Jour AWWA 65:8; 551 (August 1973).

Note: Extensive research data is provided here because of current concern with arsenic contamination.

(c) Alum $Al_2(SO_4)_3 \cdot 18\ H_2O$ as a coagulant

Laboratory tests indicate high arsenic (A_s^{+5}) removal efficiencies as indicated below.[2]

Table AS-4. Removal of Arsenic (V) by Adsorption on Hydrous Aluminum Oxide[1]

Initial pH	Dosage of Alum. $Al_2(SO_4)_3 \cdot 18H_2O$ mg/l	Arsenic Removal-per cent			
		Lost to Glassware (Control)	Lost to Glassware and Filter	Coagulation and Sedimentation	Coagulation, Sedimentation, and Filtration
5.0	10	1.45	8.74	13.6	59.0
	20	1.83	3.82	59.5	81.6
	30	2.34	6.41	77.3	90.5
	40	3.72	15.9	83.7	93.0
	50	0.37	1.28	85.3	91.7
6.0	10	1.38	8.15	69.3	74.5
	20	4.75	16.2	74 5	88.5
	30	0.21	1.22	81.0	90.5
	40	0.20	0.75	74.1	88.9
	50	1.35	6.20	85.8	93.6
7.0	10	6.50	10.3	37.4	64.5
	20	0.73	4.45	72.0	82.3
	30	8.3	12.6	74.5	84.0
	40	2.25	4.6	87.1	91.0
	50	10.9	15.2	82.4	92.0
8.0	10	2.59	7.14	6.45	18.5
	20	8.83	2.06	31.2	39.0
	30	3.33	5.85	45.0	47.0
	40	0.53	4.24	64.0	67.0
	50	2.64	6.85	62.1	65.5

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[1] Gulledge J. & O'Connor J. "Removal of Arsenic (V) From Water by Adsorption on Aluminum and Ferric Hydroxides', Jour AWWA 65:8; 551 (August 1973)

(2) Ion Exchange (Pg. 150, 228, 238)
Removal efficiency approximates 95%+
Maximum concentration in feed-water = 2.0 mg/l

(3) Distillation (Pg. 139, 228, 237)
Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 100 mg/l

(4) Electrodialysis (Pg. 128, 228, 236)
Removal efficiency approximates 80%
Maximum concentration in feed-water = .5 mg/l

(5) Reverse Osmosis (Pg. 119, 227, 235)
Removal efficiency ranges from 90-95%
Maximum concentration in feed-water ranges from 1 mg/l to 0.33 mg/l*

(6) Lime Soda Softening (Pg. 196, 240)
Effectiveness of lime soda softening in removing arsenic is dependent on arsenic concentration and pH level in water being treated. Lime soda softening will remove 90% of the arsenic from the water being treated provided the pH level is 9.5 to 10 and the untreated water arsenic levels do not exceed 1.0 mg/l. If the arsenic levels do exceed 1.0 mg/l, then the treatment efficiency drops as low as 60% under these pH conditions, and several passes through the process or additional treatment will be necessary. If the raw water arsenic concentration exceeds 1.0 mg/l, and the pH level is increased to 10.6 to 11, then 90% efficiencies can be maintained. Additional treatments will, of course, still be necessary.

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*Exact removal efficiency in this range, for a particular water supply must be determined by pilot test.

BARIUM (Ba)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 1.0 mg/l

Possible Sources of Contamination

Barium is found in many waters in the United States with concentrations ranging from 2-340 μg/l. Considerable levels may be found in some groundwaters and in effluents from areas where barytes and witherite are mined.

Barium and its salts are used in many industrial applications including metallurgy, paint manufacture, ceramic and glass manufacture and several other processes. As a result, wastes from these plants may contain significant levels of barium contamination.

Treatment Methods

(1) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 1000 mg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 97%
Maximum concentration in feed-water ranges from 10 mg/l - 33.3 mg/l*

(3) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water - 20 mg/l

(4) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water - 5 mg/l

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* Exact removal efficiency, in this range, for a particular water supply must be determined by pilot tests.

CADMIUM (Cd)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.010 mg/1

The chloride, nitrate and sulfate of cadmium are highly soluble in water, but the carbonate and hydroxide are insoluble.

Possible Sources of Contamination

Only minute traces of cadmium are found in natural waters in the United States. If abnormally high concentrations are found, industrial pollution is the most likely cause. Electroplating wastes have been found to be a major source of cadmium in the environment. Other industrial uses of cadmium which may contribute to water pollution include use in insecticides, photography, metallurgy and ceramic manufacture. If galvanized pipes or fixtures are used anywhere throughout a water supply system, cadmium may leach from these pipes and cause contamination, pH control can help to alleviate this problem.

Treatment Methods for Soluble Forms of Cadmium

(1) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 10 mg/1

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 98%
Maximum concentration in feed-water ranges from 0.1 mg/1 - 0.5 mg/1*

(3) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 0.2 mg/1

(4) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency 80%
Maximum concentration in feed-water = 0.05 mg/1

Treatment Methods for Insoluble Forms of Cadmium

(1) Coagulation and Sedimentation (Pg. 89, 192, 226, 233) followed by Filtration (Pg. 95, 226, 227, 234)
Removal efficiency is 50-90% . Maximum concentration in feed-water is 0.02 - 0.1 mg/1

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*Exact removal efficiency, in this range, for a particular water supply must be determined by pilot test.

CHROMIUM (Cr)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.05 mg/l.

The trivalent chloride, nitrate and sulfate salts are readily soluble; however, the hydroxide and carbonate are insoluble. Of the hexavalent salts only sodium, potassium, and ammonium chromates are soluble. The corresponding dichromates are also quite soluble.

Possible Sources of Contamination

Chromium salts are used extensively in the metal finishing industry, in the tanning industry and in the manufacture of paints, dyes, explosives, ceramics, paper and many other substances. Chromium compounds may also be present in the discharge of chromium treated cooling waters where chromium is used as a corrosion inhibitor.

Treatment Methods for Soluble Forms of Chromium

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 90 - 97%
Maximum concentration in feed-water ranges from 0.5 mg - 1.67 mg/l*

(2) Electrodialysis (Pg.128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water 0.25 mg/l

(3) Distillation (Pg.139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 50 mg/l

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 1 mg/l

Hexavalent Cr may be removed directly with a strong base anion exchange process or it may be converted by sulfonation to trivalent Cr.

Trivalent Cr may be removed by absorption on a cation exchange resin to levels approximating 0.05 mg/l.

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* Exact removal efficiency, in this range, for a particular water supply must be determined by pilot tests.

Treatment Methods for Insoluble Forms of Chromium

(1) Coagulation and Sedimentation (Pg. 89, 192, 226, 233) with Filtration (Pg. 95, 226, 227, 234). Removal efficiency is 50-90%. Maximum concentration in feed-water is 0.1-0.5 mg/l.

FLUORIDES (F)

1974 Drinking Water Standards and Guidelines - Approval Limits (Health) -

Annual average of maximum daily air temperatures (C°) based on temp. data obtained for a minimum of 5 years.

10.0 - 12.1	1.8 mg/l
12.2 - 14.6	1.7 mg/l
14.7 - 17.7	1.5 mg/l
17.8 - 21.4	1.4 mg/l
21.5 - 26.2	1.2 mg/l
26.3 - 32.5	1.1 mg/l

Possible Sources of Contamination

As only a few regions contain large deposits of fluoride bearing rock, fluorides in high concentrations are not common in surface waters, but they may occur in detrimental concentrations in groundwater.

Fluorides are used as insecticides, disinfectants, as a flux in steel manufacture, for preserving wood and as mucilages for the manufacture of glass and enamels. Fluorides are not normally found in industrial wastes. However, they may be present as a result of accidental spillage.

Treatment Methods[1]

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 90-97%. Maximum concentration in feed-water ranges from 11 mg/l to 60 mg/l*

(2) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%. Maximum concentration in feed-water ranges from 5.5 mg/l to 9 mg/l*

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximate 99.9%. Maximum concentration in feed-water is 1000 mg/l

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%. Maximum concentration in feed-water ranges from 22 mg/l to 37 mg/l.*

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*Exact removal efficiency in this range, for a particular water supply must be determined by pilot tests.

[1] See p. 183 for special purpose defluoridation plant descriptions.

COPPER (Cu)

1974 Drinking Water Standards and Guidelines - Approval Limits (Esthetic)- 1.0 mg/l.

Possible Sources of Contamination

Copper occurs in natural surface waters, in solution, usually below 20 mg/l. Higher concentrations are usually the result of pollution due to the corrosive action of water in copper and brass tubing, industrial effluents, and the use of copper compounds for algal control. Copper salts are used in textile manufacture, tanning, pnotography, electroplating, insecticides, fungicides and many other industrial processes.

Treatment Methods

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 90 - 97%
Maximum concentration in feed-water ranges from 10 mg/l - 33.3 mg/l*

(2) Electrodialysis (Pg. 128, 228,236)

Removal efficiency approximates 80%
Maximum concentration in feed-water - 5 mg/l

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 1000 mg/l

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 20 mg/l

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* Exact removal efficiency, in this range, for a particular water supply must be determined by pilot tests.

CYANIDE (CN)

1974 Drinking Water Standards and Guidelines - Approval Limits (Health) - 0.2 mg/l

Possible Sources of Contamination

Cyanides occur in the effluents from gas works and coke ovens, from the scrubbing of gases at steel plants, from metal cleaning and electroplating processes and from chemical industries.

In natural streams, cyanides are decomposed by bacterial action so that excessive concentrations may be expected to diminish with time.

Treatment Methods

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 90 - 97%
Maximum concentration in feed-water ranges from 2 mg/l - 6.67 mg/l*

(2) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water = 1 mg/l

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 200 mg/l

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = [illegible] mg/l

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* Exact removal efficiency in this range, for a particular water supply must be determined by pilot tests.

FOAMING AGENTS

1974 Drinking Water Standards and Guidelines - Approval Limit (Esthetic) 0.5 mg/l as Methylene Blue Active Substances.

The presence of foaming is primarily a result of synthetic detergent pollution. The major class of substances causing the foaming is the anionic surfactant. Anionic surfactants, principally linear alkyl benzene sulfonate, are measured by the methylene-blue method.

Treatment Methods

(1) Activated Carbon (Pg. 175, 239)

Removal efficiency ranges from 90 - 100%
Maximum concentration in feed water = from 5 mg/l and up*

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* Exact removal efficiency, for this range, for a particular water supply must be determined by pilot test.

ORGANICS - CARBON CHLOROFORM EXTRACT

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.7 mg/l

Carbon Chloroform Extract (CCE) indicates the presence of stable organic compounds in water sources. The extract has an operational definition and is a mixture of organic compounds that can be adsorbed onto activated carbon under specific controls and then adsorbed with organic solvents under specific controls. Examples of substances measured with these methods include substituted benzene compounds, kerosene, polycyclic hydrocarbons, phenylether and insecticides.

Possible Sources of Contamination

Most surface waters receive a large, time varying, and often untraceable, load of organic chemicals. Possible sources of contamination include natural organic decay materials, agricultural runoff, domestic sewage, accidental chemical spills and various industrial wastes.

Treatment Methods

(1) Reverse Osmosis (Pg.119, 227, 235)

Removal efficiency approximates 99%, if molecular weight of contaminant is greater than 200.
Maximum concentration in feed-water = 70 mg/l

(2) Activated Carbon (Ref. No. 108, 180) (Pg.175, 239)

Removal efficiency depends on several factors including water temperature, initial amount of contaminant and size of contaminant. As a result, percentage removals must be determined by laboratory testing.

LEAD (Pb)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.05 mg/l

Various lead salts (e.g., $PbCl_2$) are highly soluble in water. However, the carbonate and hydroxide are insoluble and the sulfate is only slightly soluble.

Possible Sources of Contamination

In areas where limestone galena are found, natural waters have been known to contain as much as 0.4-0.8 mg/l of lead. As this situation is rare, the most likely sources of lead pollution are industrial and mining effluents and even more commonly if lead piping is used for water supply or distribution systems where raw and finished water may be allowed to stand for several hours. If contamination is due to lead pipes, it can best be controlled by pipe removal. Where this action is not feasible, pH control and stabilization is the alternative. (See Page 189). The extensive use of lead compounds in gasoline has significantly increased the availability of lead for solution in surface waters. In such cases and when contamination is not due to lead piping the following treatment methods will apply.

Treatment Methods

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 99%
Maximum concentration in feed-water ranges from 0.5 mg/l - 5.0 mg/l*

(2) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water = 0.25 mg/l

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 50 mg/l

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 1.0 mg/l

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* Exact removal efficiency, in this range, for a particular water supply must be determined by pilot tests.

IRON (Fe) and MANGANESE (Mn)

1974 Drinking Water Standards and Guidelines - Approval Limit (Esthetic)
Iron - 0.3 mg/l Manganese - 0.05 mg/l

Ferric (Fe^{++}) and ferrous (Fe^{+++}) iron are highly soluble in water. However, when oxidation occurs, as in surface waters, both forms become insoluble hydroxides. These precipitates are removed from the water and, as a result, the concentrations of iron in well-aerated surface water is usually low.

Manganese metal is not found pure in nature, but its ores are very common and widely distributed. Like iron, it occurs in the divalent and trivalent forms. The chlorides, nitrates, and sulfates of manganese are highly soluble in water. The oxides, carbonates and sulfates are only slightly soluble; as a result, manganese concentrations in well-aerated surface waters are rarely over 1.0 mg/l. In groundwater under reducing conditions manganese concentrations may be high. Manganese frequently accompanies iron in such ground waters.

Possible Sources of Iron Contamination

Natural water may be contaminated by iron-bearing industrial wastes and by the leaching of soluble iron salts from soil and mineral deposits, e.g., acid mine drainage and iron-bearing groundwater. In addition, iron and its alloys are corroded by water in the presence of oxygen. The products of corrosion become pollutants.

Possible Sources of Manganese Contamination

High concentrations of manganese may be leached from mineral deposits, resulting in the high manganese levels found in groundwater. In addition, manganese and its salts (e.g. $MnCl_2$) are used in the manufacture of paints, steel, glass and various other materials. Manganese is utilized in agriculture to enrich manganese deficient soils and may enter water sources with runoff.

Treatment Methods

(1) Aeration [1] (Pg. 71, 225, 231)

Since iron and manganese are generally held in water supplies as the bicarbonate by dissolved CO_2, aeration will release the CO_2, and the increase in dissolved oxygen will partially precipitate the iron and manganese as hydrous oxides. The process also removes other volatile gases such as hydrogen sulfide. Aeration is usually followed by sedimentation and sand filtration. High concentrations of iron can be reduced to less than 0.1 mg/l by this method. When removal of all CO_2 is required, the solution must be neutralized with lime or other alkali before filtration through sand or anthracite beds.

Hale (I.E.C. 6, 632 August 1914) reported that 0.24 mg/l of oxygen will precipitate 1 mg/l of iron; 0.29 mg/l is required for 1 mg/l of manganese. Organic bound iron such as ferric humates will not be removed by aeration, and chemical precipitation is required for this type of material.

(2) Slow Sand Filtration (Pg. 96, 227, 232, 234)

Removal efficiency approximates 90%
Maximum concentration of iron in feed-water = 3 mg/l
Maximum concentration of manganese in feed-water = 0.5 mg/l

(3) Coagulation (Pg. 82, 192, 232)

Chemical precipitation of iron and manganese at pH values approximating their isoelectric point of pH = 9.4 produces quantitative removal of manganese.

Therefore, coagulation followed by sedimentation and filtration will produce a water free from these elements.

Addition of 1 mg/l of alum is frequently necessary to coagulate well waters having an iron content of 10 to 20 mg/l. Introduction of the alum nuclei particles produces a more compact, stable floc.

(4) Reverse Osmosis (Ref. No. 133) (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 99.5%
Maximum concentration of iron in feed-water ranges from 3 - 60 mg/l*
Maximum concentration of manganese in feed-water range from 0.5 - 10 mg/l*

(5) Electrodialysis (Ref. No. 133) (Pg.128, 228, 236)

Removal efficiency appproximates 80%
Maximum concentration of iron in feed-water = 1.5 mg/l
Maximum concentration of manganese in feed-water = .25 mg/l

(6) Distillation (Ref. No. 133) (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration of iron in feed-water = 300 mg/l
Maximum concentration of manganese in feed-water = 50 mg/l

(7) Ion Exchange (Ref. No. 133, 172) (Pg.150, 228, 238)

Removal efficiency approximates 95%

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*Exact removal efficiency, in these ranges, for a particular water supply must be determined by pilot tests.

Maximum concentration of iron in feed-water = 6 mg/l
Maximum concentration of manganese in feed-water = 1 mg/l

(8) Diatomite Filtration[1] (Pg. 96, 227, 234)

(a) Iron removals to 0.1 mg/l are possible with preaeration and alkalinity adjustment to precipitate oxide particles. Recent work done by the Commonwealth of Massachusetts has shown iron may also be removed from solution by the use of magnesite (MgO) with 5-10 minutes reaction time and final diatomite filtration.

(b) Manganese Removal - Manganese removal with preoxidation to 0.05 mg/l is possible with diatomite filtration. Potassium permanganate is normally used as the oxidizing agent.

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[1] Reference - Erickson, D.L. & Veatch, Jr., N.T. - Iron and Manganese Removal. JAWWA. 29:12:1896 (December, 1937).

MERCURY (Hg)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health)
0.002 mg/1

Possible Sources of Contamination

Organic mercury compounds (e.g., pyridylmercuric acetate) are used in herbicides and fungicides. Many of the highly soluble mercury salts, e.g., mercuric nitrate, are used as explosives, antiseptics, in printing, in electroplating and in numerous other processes which may produce mercury bearing effluents.

Treatment Methods[1]

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 97%.
Maximum concentration in feed-water ranges from 0.02 - 0.067 mg/1*

(2) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%.
Maximum concentration in feed-water = 0.01 mg/1

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99%.
Maximum concentration in feed-water - 0.2 mg/1

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%.
Maximum concentration in feed-water = 0.04 mg/1

(5) Diatomite Filtration (Pg. 96, 227, 234).

Chemicals such as sodium sulfide and sodium borohydride are used to reduce mercuric compounds which are then precipitated out. Removals down to 0.004 - 0.006 mg/1 have been achieved.

The following data was obtained from laboratory studies by G.S. Logsdon and J.M. Symons, both of the Standards Attainment Branch, Water Supply Research Laboratory, National Environmental Research Center, United States Environmental

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* Exact removal efficiency, in this range, for a particular water supply must be determined by pilot tests.

[1] Extensive research data is presented here because of the topical nature of mercury contamination.

Protection Agency. Since the work was done as bench scale laboratory research, the results can be extrapolated only to a limited extent with regard to full scale continuously operated treatment plants. However, the results indicate general trends and suggest possible treatment methods.

(6) Coagulation [1] (Pg. 82,193, 232)

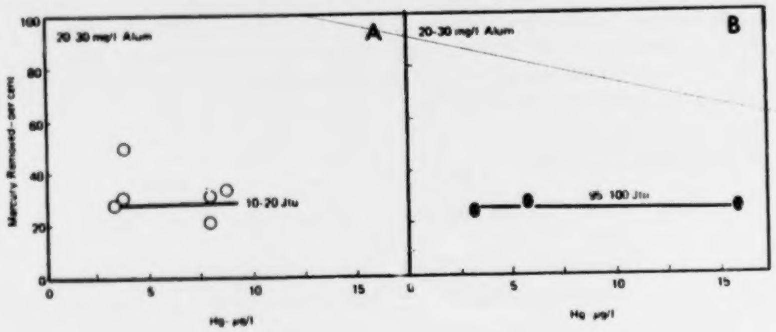

Figure Hg 1. Effect of Initial Mercury Concentration on Removal Percentage Using Alum Coagulation.

A - inorganic mercury coagulated with alum
B - methyl mercury coagulated with alum

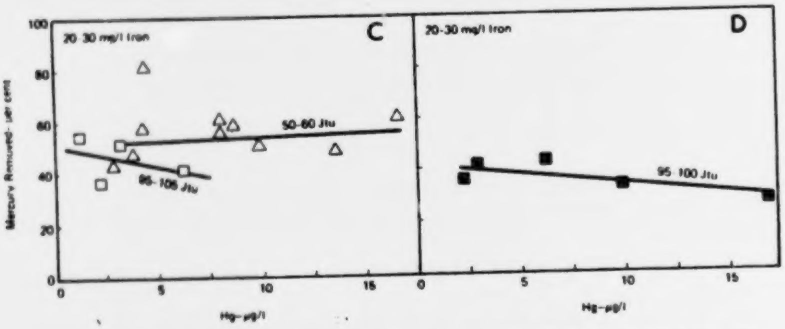

Figure Hg 2. Effect of Initial Mercury Concentration on Removal Percentage Using Iron Coagulation

C - inorganic mercury coagulated with iron
D - methyl mercury coagulated with iron

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[1] Reference - Logsdon G & Symons, J - Mercury removal by Conventional water - Treatment Techniques - JAWWA 65:8:554 (August 1973)

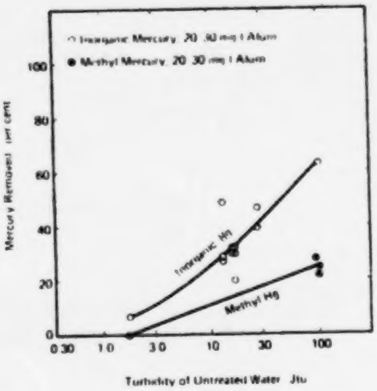

Figure Hg 3. Turbidity vs. Mercury Removal by Alum Coagulation

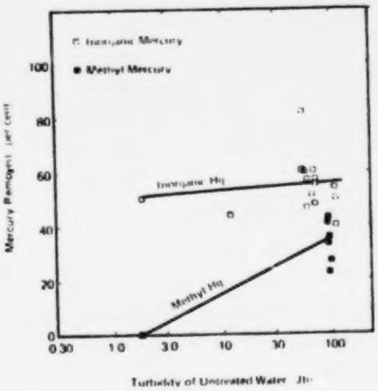

Figure Hg 4. Turbidity vs. Mercury Removal by Iron Coagulation

(7) Softening (Pg. 196, 240)

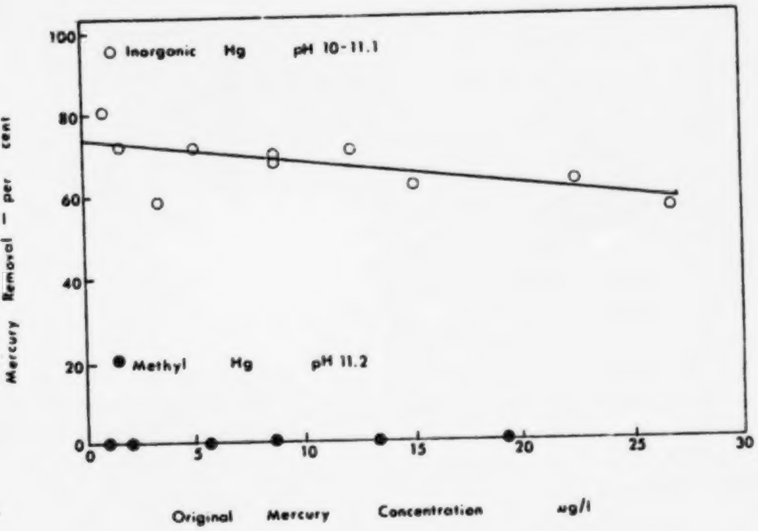

Figure Hg 5. Effect of Mercury Concentration on Removal by Lime Softening

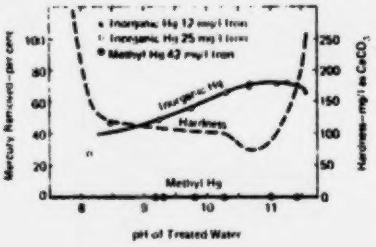

Figure Hg 6. Mercury Removal by Lime Softening with Supplementary Coagulation

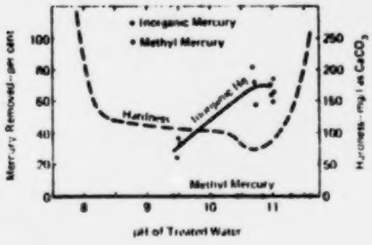

Figure Hg 7. Mercury Removal by Lime Softening. No Supplementary Coagulation.

(8) Activated Carbon

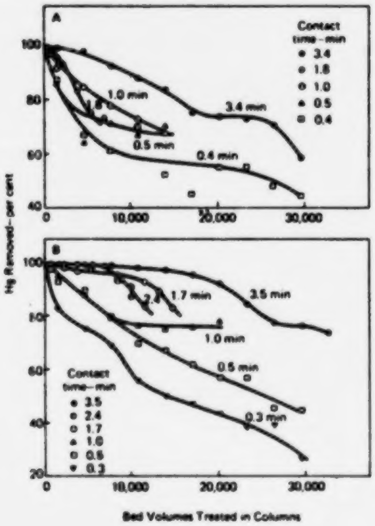

Figure Hg 8. Mercury Removal by Granular Activated Carbon Columns

A - inorganic
B - methyl mercury

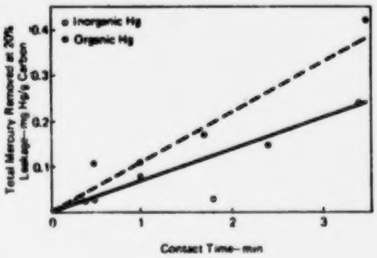

Figure Hg 9. Effect on Contact Time on Capacity of Granular Activated Carbon for Mercury.

NITRATES (NO_3)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 10 mg/l

Water with nitrite - nitrogen concentrations over 1 mg/l should not be used for infant feeding.

Possible Sources of Contamination

Nitrates occur in polluted waters that have undergone self-purification or aerobic treatment processes. Ground waters may acquire nitrates by percolation in areas using nitrates for fertilizers and by leachings from cesspools. In addition, nitrates may be added to a stream or groundwater that receives inorganic industrial wastes, particularly wastes from chemical fertilizer-producing plants.

Treatment Methods

(1) Reverse Osmosis (Ref. Nos. 10, 53) (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 97%
Maximum concentration in feed-water ranges from 100 - 333.3 mg/l*

(2) Electrodialysis (Ref. Nos. 10, 53) (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water = 50 mg/l

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 10,000 mg/l

(4) Ion Exchange (Ref. Nos. 10, 53, 161) (Pg. 150, 228, 238)

Removal efficiency approximates 96%
Maximum concentration in feed-water = 250 mg/l

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* Exact removal efficiency, in this range, for a particular water supply must be determined by pilot tests.

SELENIUM (Se)

1974 Drinking Water Standard and Guidelines - Approval Limit (Health) - 0.01 mg/l.

Possible Sources of Contamination

Some areas of South Dakota and Wyoming have soils containing up to .003% by weight of selenium. Irrigation return flows from selenium bearing soils may contain undesirably high levels of contamination. In addition, selenium has a wide variety of industrial uses where waste problems may occur. These uses include paint manufacture, dye manufacture, insecticide production and rubber manufacture.

Treatment Methods

(1) Coagulation with Sedimentation (Pg. 89, 192, 226, 233)

Removal efficiencies are:

Se^{+4}: 60 - 90% removal
Se^{+6}: 0 - 30% removal

Maximum concentrations in feed-water are:

Se^{+4}: .1 mg/l
Se^{+6}: 0.015 mg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 97%
Maximum concentration in feed-water range from 0.1 mg/l - 0.3 mg/l*

(3) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water = 0.05 mg/l

(4) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 10 mg/l

(5) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 0.2 mg/l

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*Exact removal efficiency, in these ranges, for a particular water supply, must be determined by pilot tests.

(6) Softening (Pg. 196, 240)

At pH of 10.6 - 11, removal efficiencies are:

Se^{+4} - 60 - 90% removal
Se^{+6} - 0 - 30% removal

Maximum concentrations in feed-water are:

Se^{+4} - .025 mg/1 - 0.1 mg/1*
Se^{+6} - 0 mg/1 - .015 mg/1

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*Exact removal efficiency, in these ranges, for a particular water supply, must be determined by pilot tests.

SILVER (Ag)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.05 mg/l.

Many of the silver salts such as the chloride, sulfide, phosphate and arsenate are insoluble.

Possible Sources of Contamination

Silver ions may be leached from the naturally occurring silver ores; however, due to insolubility of the salts, the ion concentration should be low. Silver and its related compounds are used in numerous industrial processes from which silver may be introduced into the environment in wastes. These processes include photography, ink manufacture, electroplating and food and beverage processing. About 30% of the U.S. industrial consumption of silver is used in photography, with silver nitrate $AgNO_3$ the primary compound.

Treatment Methods

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 97%
Maximum concentration in feed-water range from
0.5 mg/l - 1.5 mg/l*

(2) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water = 0.25 mg/l

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 50 mg/l

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 1.0 mg/l

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*Exact removal efficiency, in this range, for a particular water supply, must be determined by pilot tests.

SODIUM (Na)

The 1974 Drinking Water Standards and Guidelines provide for no specific limits on Sodium - See Appendix B page 305 for discussion.

Possible Sources of Contamination

Due to the abundance of sodium bearing compounds and their extreme solubility, high sodium ion concentrations are not uncommon in natural waters. Another major source of sodium ion contamination is sea water intrusion in coastal areas. In addition to natural sources, sodium is the cation of many industrial salts and as such is one of the most common ions in process wastes.

Treatment Methods

(1) Reverse Osmosis (Ref. No. 10) (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 99%.

(2) Electrodialysis (Ref. No. 10) (Pg. 128, 228, 236)

Removal efficiency approximates 80%.

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99%.

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%.

SULFATES (SO_4)

1974 Drinking Water Standards and Guidelines - Approval Limit (Esthetics)- 250 mg/1.

The sulfates of lead, barium, strontium and calcium are relatively insoluble; however, sodium, potassium, and ammonium sulfates are highly soluble.

Possible Sources of Contamination

Natural waters may contain sulfates as a result of leachings from gypsum and other common minerals. In addition, the final oxidation of sulfides, sulfites, and thiosulfates in surface waters yield sulfates. Sulfates may also enter water sources in numerous industrial wastes such as those from tanneries, sulfate-pulp mills, textile mills and other plants that use sulfates or sulfuric acid.

Treatment Methods

(1) Reverse Osmosis (Ref. No. 10) (Pg. 119, 227, 235)

Removal efficiency approximates 99%
Maximum concentration in feed-water = 25,000 mg/1.

(2) Electrodialysis (Ref. No. 10) (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water = 1,250 mg/1.

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99.9%
Maximum concentration in feed-water = 250,000 mg/1.

(4) Ion Exchange (Ref. No. 10) (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 5,000 mg/1.

ZINC (Zn)

1974 Drinking Water Standards and Guidelines - Approval Limit (Esthetics)- 5 mg/l.

Some zinc salts (e.g. chloride, zinc sulfate) are highly soluble while other salts (e.g. zinc carbonate, zinc sulfide) are insoluble in water.

Possible Sources of Contamination

Zinc occurs abundantly in rocks and ores and has been found in high concentrations in waters draining zinc mining areas. However, since zinc is absorbed to a large extent in hydrolyzate sediments and in soils, it is rarely found above the trace level in natural waters. Industrial uses of zinc salts which may contribute wastes to water sources include the manufacture of dyes, pigments, insecticides, and the galvanizing process.

Treatment Methods

(1) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency ranges from 90 - 97%
Maximum concentration in feed-water ranges from
50 mg/l - 166.67 mg/l*

(2) Electrodialysis (Pg. 128, 228, 236)

Removal efficiency approximates 80%
Maximum concentration in feed-water = 25 mg/l.

(3) Distillation (Pg. 139, 228, 237)

Removal efficiency approximates 99%
Maximum concentration in feed-water = 500 mg/l.

(4) Ion Exchange (Pg. 150, 228, 238)

Removal efficiency approximates 95%
Maximum concentration in feed-water = 100 mg/l.

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*Exact removal efficiency, in this range, for a particular water supply, must be determined by pilot tests.

ALDRIN

1974 Drinking Water Standards and Guidelines - Approved Limit (Health) - 0.00000014 mg/1.

Classification:	A chlorinated hydrocarbon
Trade names & Code #s:	Compound 118 (Shell), HHDN, Octalene
Technical product:	The technical product is a tan to dark brown solid with a melting point range of 49-60°C. It contains not less than 95% of the pure product.
Comments:	Aldrin undergoes biological oxidation to yield dieldrin.
Use:	Insecticide showing contact and stomach poison action with particular effect against soil insects.
Companies:	Shell Development Co., Universal Oil Products.

Treatment Methods

(1) Activated Carbon (Ref. No. 108) (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 0.000014 mg/1

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 0.00014 mg/1

CHLORDANE

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 3 $\mu g/l$

Classification: A chlorinated hydrocarbon.

Trade names & Code #s: CD-68, Octachlor, Octa-Klor. M-410, Toxichlor, Velsicol 1068. The name Chlordane is registered with U.S. Patent Office as a common name for public use.

Comments: The commercial product, as an insecticide, is a mixture of 60-75% isomeric forms of chlordane and 20-40% related compounds such as heptachlor and chlordane.

Use: Insecticide showing contact, stomach poison and fumigant action with residual effects. Used against earthworms, fleas, lice, ticks and mange.

Companies: Velsicol Corp.

Treatment Methods

(1) Activated Carbon (Ref. No. 108) (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 300 $\mu g/l$

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 300 $\mu g/l$

DDT

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 50 μg/l

Classification: A chlorinated hydrocarbon.

Trade names & Code #s: Accotox, Anofex, Chlorophenothene, Dinocide, DND, Gesapon, Gesarex, Gesarol, Guesapon, Guesarol, Gyron, GNB, GNB-A, Ixodex, Necocid, Neocidol (Geigy), Pentachlorin, Sillortox, Zerdane.

Technical product: The technical product is a waxy solid of indefinite mp and of similar solubility to the pure compound. It is a mixture of p,p' DDT and two isomers o,p' DDT and o,o' DDT. The isomers are less toxic than the pure compound.

Use: Insecticide showing contact and stomach poison action with long residual effects. Used against Anopheles. Use of DDT is prohibited in the United States except in cases of extreme emergency due to its extreme residual effects.

Companies: Geigy Chemicals.

Treatment Methods

(1) Activated Carbon (Ref. No. 108, 139) (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 5,000 μg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 5,000 μg/l

DIELDRIN

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.00014 µg/l

Classification: A chlorinated hydrocarbon.

Trade names & Code #s: Compound 497 (Shell), HEOD, Octalox.

Technical product: The technical product is buff to light brown flakes of setting point[1] not below 95°C.

Use: Insecticide showing contact and stomach poison activity.

Companies: Shell Development Co.

Treatment Methods

(1) Activated Carbon (Ref. No. 139) (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 0.014 µg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 0.014 µg/l

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[1] Setting point is the temperature at which the pure compound starts to solidify from the liquid form under laboratory conditions.

ENDRIN

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.2 μg/l

Classification: A chlorinated hydrocarbon.

Trade names & Code #s: Compound 269, Exptl. Insecticide #269 (Velsicol).

Comments: Endrin is an isomer of dieldrin.

Use: Insecticide showing contact and stomach poison activity.

Companies: Shell Development Co., Velsicol Chemical Co.

Treatment Methods

(1) Activated Carbon (Ref. No. 139) (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 20 μg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 20 μg/l

HEPTACHLOR EPOXIDE

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.1 μg/l

Classification: A chlorinated hydrocarbon.

Trade names & Code #s: Velsicol 53-cs-17.

Use: Pesticide.

Companies: Velsicol Chemical Corp.

Treatment Methods

(1) Activated Carbon (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 10 μg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 10 μg/l

LINDANE

1974 Drinking Water Standard and Guidelines - Approval Limit (Health) - 5.0 μg/l

Classification:	A chlorinated hydrocarbon.
Trade names & Code #s:	Aparasin, Aphtiria, Benesan, Ben-Hex, BHC, Gamexane, Gamma BHC, gamma benzene hexachloride, Gammexene, Gexane, HCCH, HCH, Isotox, Jacutin, Kwell, Lorexane, Oko, Streunex, Tri-6, Vitron, 666.
Comments:	There are 8 stereoisomers of 1, 2, 3, 4, 5, 6-hexachlorocyclohexane. The gamma isomer is the most effective insecticide and is the one discussed in this report.
Use:	Insecticide showing contact, stomach poison and fumigant action with long residual effects. Parasiticide for ectoparasite.
Companies:	Chevron Chemical Co., Imperial Chemical Ind., Ltd.

Treatment Methods

(1) Activated Carbon (Ref. No. 139) (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 500 μg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 500 μg/l

METHOXYCHLOR

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 100 μg/1

Classification: A chlorinated hydrocarbon.

Trade names & Code #s: Dimethoxy DT, DMDT, Marlate, Methoxcide, Methoxo, Methoxy-DDT.

Technical product: The technical product is a mixture of 88% p,p' isomer and 12% related compounds, such as the o,p' isomer. It has a setting point of 77°C. and is practically insoluble in water, moderately soluble in ethanol, petroleum oils and soluble in most aromatic solvents.

Use: Insecticide showing contact and stomach poison action with long residual effects. Parasiticide for control of certain ectoparasites of cattle, sheep and goats.

Companies: E. I. DuPont de Nemours & Co., Geigy Agriculture Chemicals.

Treatment Methods

(1) Activated Carbon (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 10,000 μg/1

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 10,000 μg/1

TOXAPHENE

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 5.0 μg/l

Classification:	A chlorinated hydrocarbon.
Comments:	Toxaphene is a mixture of polychlorobicyclic terpenes with chlorinated camphene predominating. The total chlorine content is 67-69%.
Use:	Insecticide showing contact and stomach poison action. Used against army worms, boll weevil, bollworm, cotton aphid, cotton fleahopper, cotton leafworm, grasshopper, rapid plant bug, southern green stink bug, tarnish plant bug, thrips.
Companies:	Hercules Powder Co.

Treatment Methods

(1) Activated Carbon (Ref. No. 108) (Pg. 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 500 μg/l

(2) Reverse Osmosis (Pg. 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 500 μg/l

2,4 - 5 - TP (Silvex)

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) - 0.03 mg/l.

Trade names:	Kuron: mixed propylene glycol ether esters. Kurosal: the potassium salt. Fenoprop.
Use:	Hormone type week killer for bush control, for control of submergent and emergent aquatic weeds and for weed control on certain crops.
Companies:	Dow Chemical Company.

Treatment Methods

(1) Activated Carbon (Page 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 3 mg/l.

(2) Reverse Osmosis (Page 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 3 mg/l.

2,4 - D

1974 Drinking Water Standard and Guidelines - Approval Limit (Health) - 0.1 mg/l.

Trade names:	2 4 D.
Use:	Weed killer for cereals and other crops.

Treatment Methods

(1) Activated Carbon (Ref. No. 108, 174) (Page 175, 239)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 10 mg/l

(2) Reverse Osmosis (Page 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 10 mg/l

COMMON ORGANOPHOSPHATES

1974 Drinking Water Standards and Guidelines - Approval Limit (Health) -

0.1 mg of parathion per liter, or the equivalent concentration of organophosphate insecticides based on total organic phosphorus, as determined by suitable chemical or physicochemical method(s).

Provided the total concentration of organophosphate insecticides exceeds 0.1 mg/l as parathion then an analytical gas liquid chromatographic procedure should be employed to determine specific organophosphate insecticides that are likely to occur in water supplies, examples of which follow:

Coumaphos, Dimethoate, Dichlorvos, Diazion, Disulfoton, EPN, Ethion, Azinphos Methyl, Malathion, Methyl parathion, Mevinphos, Parathion, Phorate, Ronnel, Demeton, Carbonphenothion.

Trade names & Code #s: Co-Ral, DDVP, Di-Syston, Guthion, Phosdrin, Systox, Trithion.

The ever-increasing use of biodegradable organophosphate insecticides with subsequent intrusion into ground and subsurface waters necessitates the establishment of appropriate limits to protect public health. These insecticides have a high acute mammalian toxicity mediated principally through the dysfunction of neurotransmitter mechanisms.

Companies: Chemagro Corp., Chevron Chemical Corp., and others.

Treatment Methods

(1) Activated Carbon (Page 175, 239)

Removal efficiency approximates 50% - 99% +
Maximum concentration in feed-water ranges from 0.2 mg/l - 10 mg/l*

(2) Reverse Osmosis (Page 119, 227, 235)

Removal efficiency approximates 99% +
Maximum concentration in feed-water = 10 mg/l.

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*Exact removal efficiency, in this range, for a particular water supply must be determined by pilot tests.

RADIOACTIVE CONTAMINANTS

1974 Federal Drinking Water Standards and Guidelines - Approval Limit (Health) -

Constituent	Approval Limit (Health)
Radioactivity	
Radium 226, Radium 228 and other Alpha particle emitters[1]	
Gross Alpha particle activity (including Radium 226)	15 pCi/l
Radium 226 and/or Radium 228	5 pCi/l

Constituent	Approval Limit (Health)
Beta particle and Photon activity from artificial radionuclides[2]	
Tritium	8×10^4 pCi/l
Strontium 90	8 pCi/l
Iodine 129 and/or Iodine 131	2 pCi/l

Damage to human tissue from radioactive contamination occurs both on the short term and long term. No body injury may be discernible with a symptom free period of a few months to many years. Tissue may not recover from damage, even if exposure is slight, since there may be chromosomatic or genetic changes. Radium ingestion is cumulative with effects similar to those of lead.

Total or gross Alpha particle activity, including Radium 226, has an Approval Limit of 15 pCi/l. In addition, any combination of Radium 226 or Radium 228 should not exceed 5 pCi/l. In the same manner, the Beta particle and Photon activity from any combination of Iodine 129 or Iodine 131 should not exceed 2 pCi/l. Aggregate dose limits for water supply systems are set for both Alpha and Beta emitters and these must be considered in addition to individual contaminant limits. It must be kept in mind that once radioactive contaminants are removed from the water supply, the sludge or waste material will be radioactive and special disposal methods may be required.

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[1] Aggregate dose limit for any water supply system shall not exceed 3000 organ-rem/yr.

[2] Aggregate dose limit for any water supply system shall not exceed 1500 man-rem/yr. In no case, however, shall concentration produce in any individual a yearly dose to the total body or any internal organ greater than 0.015 rem/yr.

(a) Alpha Emitters

GROSS ALPHA

Alpha emitters radiate relatively large, highly damaging, positively charged nuclei of the helium atom. Examples of this type of emitter include the radio-isotopes of plutonium, curium and uranium. Alpha activity is produced by all nuclear chain reactions. Modes of entrance to the aqueous environment include fallout from nuclear weapons testing, nuclear fuel processing wastes, use of radionuclides for industrial purposes and the natural decay of radioactive minerals.

Treatment Methods

(1) Coagulation (Ref. No. 122) (Pg. 82, 89, 95, 232)

Coagulation combined with sedimentation and filtration will result in 20 - 80% removal. Maximum concentration that can be treated in feed-water ranges from 18.75 pCi/l to 75 pCi/l. Specific removals will have to be determined by pilot studies.

RADIUM 226 and RADIUM 228

Virtually all water sources contain radium, a radioactive daughter product of uranium, in trace amounts. Groundwaters tend to be higher in radium content with certain Midwest water supplies containing from 0.03 - 37.0 pCi/l. From the time of its discovery radium was widely used for commercial and medical purposes and careless disposal led to local contamination. Recently, however, the discovery of less expensive radionuclides and more stringent controls have virtually eliminated pollution from this source. The half-life of Radium 226 is approximately 1,620 years.

Treatment Methods

(1) Ion Exchange (Pg. 150, 228, 238)

Removal efficiencies for zeolite ion exchange approximates 96.8%.
Maximum concentration in feed-water = 156.25 pCi/l.

(2) Coagulation (Ref. No. 122) (Pg. 82, 192, 232)

Coagulation combined with sedimentation and filtration provide up to 25% removal.
Maximum concentration in feed-water = 6.67 pCi/l.

(3) Softening (Ref. No. 128) (Pg. 196, 240)

Removal efficiencies up to 75% are possible.
Maximum concentration in feed-water = 20 pCi/l.

(b) Beta Emitters

GROSS BETA

Before the advent of nuclear testing, all Beta activity was produced by naturally occurring Beta emitting nuclides such as potassium 40. Nuclear testing, particularly in the atmosphere, has substantially increased Beta radiation levels in surface waters. Examples of long-lived Beta emitting nuclides are cesium 137, cerium 144 and ruthenium 106.

Treatment Methods

(1) Coagulation (Ref. No. 122) (Pg. 82, 192, 232)

Coagulation followed by sedimentation and filtration will provide 20 - 80% removal. Maximum concentration in feed-water shall not exceed a range of 1875 man-rem/yr. to 7500 man-rem/yr. For more exact removals and applicable treatment processes it will be necessary to determine exactly which radionuclides are present in the water source.

STRONTIUM 90 (Sr-90)

The primary source of strontium 90 entering the aqueous environment is fallout from nuclear testing; however, significant amounts may be contributed to the environment by wastes from nuclear fuel processing. The half-life of Sr-90 is approximately 29 years.

Treatment Methods

(1) Coagulation (Ref. No. 122, 125, 128) (Pg. 82, 192, 232)

Alum-floc water treatment provides an average of 80% removal. Maximum concentration in feed-water = 40 pCi/l.

(2) Softening (Ref. No. 124, 126, 128) (Pg. 196, 240)

The lime-soda process employed by Oak Ridge National Laboratory where calcium and strontium are co-precipitated produces Sr-90 removals of 96%. However, it must be realized that the water undergoing this process was of high purity before its radioactive contamination.
Maximum concentration in feed-water = 200 pCi/l.

(3) Ion Exchange (Pg. 150, 228, 238)

Ion exchange resins used at various nuclear installations have been extremely successful at providing Decontamination Factors (DF) greater than 1000 $(DF = \frac{\text{Feed Concentration}}{\text{Product Concentration}})$.

However, the water passing through the exchange columns was of high purity prior to radioactive contamination enhancing the ion exchange capabilities of the exchange resin.

IODINE 129 (I-129) and IODINE 131 (I-131)

The two major sources of Iodine 129 in water are fallout from nuclear weapons testing and the discharge of wastes from nuclear fuel reprocessing plants. The extremely long half-life of 17 million years makes Iodine 129 buildup a potentially serious problem.

The short half-life of Iodine 131 (8 days) makes it a transient member of the aqueous environment. The most constant sources of contamination are disposal after medical diagnostic use and the liquid waste from nuclear power plants. Nuclear weapons testing may temporarily raise the Iodine 131 levels in water supplies; however, this contribution has been infrequent in the past few years.

Treatment Methods

(1) Coagulation (Ref. No. 122, 128) (Pg. 82, 192, 232)

Coagulation followed by sedimentation and filtration provides 20% removal. (Pg. 89, 226, 231)
Maximum concentration in feed-water = 2.5 pCi/l.

TRITIUM (H-3)

The half-life of tritium is approximately 12 years. Since it closely follows the reactions of ordinary hydrogen it is readily assimilated into water. The three major sources of tritium are cosmic ray interactions with nitrogen and oxygen in the atmosphere, nuclear testing, and releases from nuclear fuel processing plants. At present, nuclear power industry production of tritium is small compared with natural production and fallout. It is estimated that this will be the case until 1995 at which time reactor production will become the prominent source.

There are no known methods for removing tritium from water.

Note: Treatment efficiencies for which no references have been provided were obtained by personal liaison with various chemical and equipment manufacturers and dealers. A number of recognized authorities in the field of water treatment were also consulted.

Table RC-1. RADIATION UNITS

Name	Symbol	Unit of	Defined as
Curie	Ci	disintegration rate	3.7×10^{10} disintegrations per second
Picocurie	pCi	disintegration rate	.037 disintegrations per second
Roentgen	r	radiation flux	amount of X-radiation that would ionize dry air at S.T.P.
Rad		absorbed dose	100 ergs energy released per gram of any absorber
Roentgen Equivalent Physical	rep	absorbed dose in tissue	93 ergs/cm^3 in tissue
Roentgen Equivalent Man	rem	effective biological dose (radiation damage in human tissue)	(dose in rad X relative biological effectiveness)

SECTION III

METHODS OF WATER SOURCE PROTECTION

GROUNDWATER SOURCE

Protection of the water quality in aquifers which are being used or may be used in the future as a municipal water source is of primary importance. Once an aquifer has been contaminated, it is virtually impossible to remove the contaminant except by expensive water treatment processes after the water has been pumped from the ground. In many types of aquifers, particularly limestone, the development of fissures and solution cavities enable pollutants to travel long distances if they enter the aquifer.

Ground waters generally do not contain bacteria. However, in some instances shallow groundwaters have become contaminated with pathogenic bacteria. Sources of this contamination include the underground disposal of inadequately treated human sewage and the percolation of animal wastes from farm yards and feeding lots. Should these wastes come into contact with water supplying a well field, the transmission of such diseases as typhoid fever, cholera, dysentery, diarrhea, salmonella and infectious hepatitis could occur. In addition to bacteria, these waters contain undesirably high levels of nutrients (i.e., nitrates and phosphates) and in some cases heavy metals (i.e., Zn, As) which can enter a shallow well field with normal groundwater flow and cause serious health problems.

Underground industrial waste disposal is another potential pollution source for groundwaters in the United States. Metal plating and paper manufacturing wastes are examples of pollutants disposed of in this manner. Dissolved materials such as hexavalent chromium, cyanide, copper, zinc and other toxic materials from industrial sources may contaminate ground waters which otherwise would be potable. Less dangerous industrial wastes disposed of in this manner may cause color, taste and odor problems.

The return to aquifers of waters warmed in industrial cooling processes and the recharging of groundwaters with contaminated surface runoff can result in further groundwater pollution. This problem is extremely important in agricultural areas where herbicides, pesticides and fertilizers may be dissolved by storm runoff and percolate into the water table.

The subsurface emplacement of fluids by well injection is viewed negatively by the Environmental Protection Agency and the Agency "encourages development of alternate means of disposal which afford greater environmental protection".[1]

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[1] See United States Environmental Protection Agency Administrator's Dicision Statement No. 5 in Appendix D page No. 321.

The most obvious solution to prevent the pollution of groundwaters by underground waste disposal is to place the waste material in nonwater-bearing ground formations. Since this situation is never completely possible, it is necessary to locate disposal sites a safe distance from well fields. A safe distance depends on the nature of the surrounding rock and soil formation (i.e., their thickness and permeability) and the direction of the water flow in nearby aquifers. For maximum protection, waste disposal sites should be located so that any contamination of groundwaters that occurs will move away from existing or planned well fields. The AWWA Ground Water Manual states that "Experience has shown that the average safe distance between wells in sand or gravel or sandstone and sources of bacterial pollution such as sewers, septic tanks, etc., is 61 meters. Where bacterial pollution is introduced directly into a saturated aquifer the safe distance may be much greater." This distance would not apply to pollution from dissolved contaminants. Dissolved materials, e.g., pesticides, would travel unobstructed for much greater distances, as natural filtration would have no effect on them.

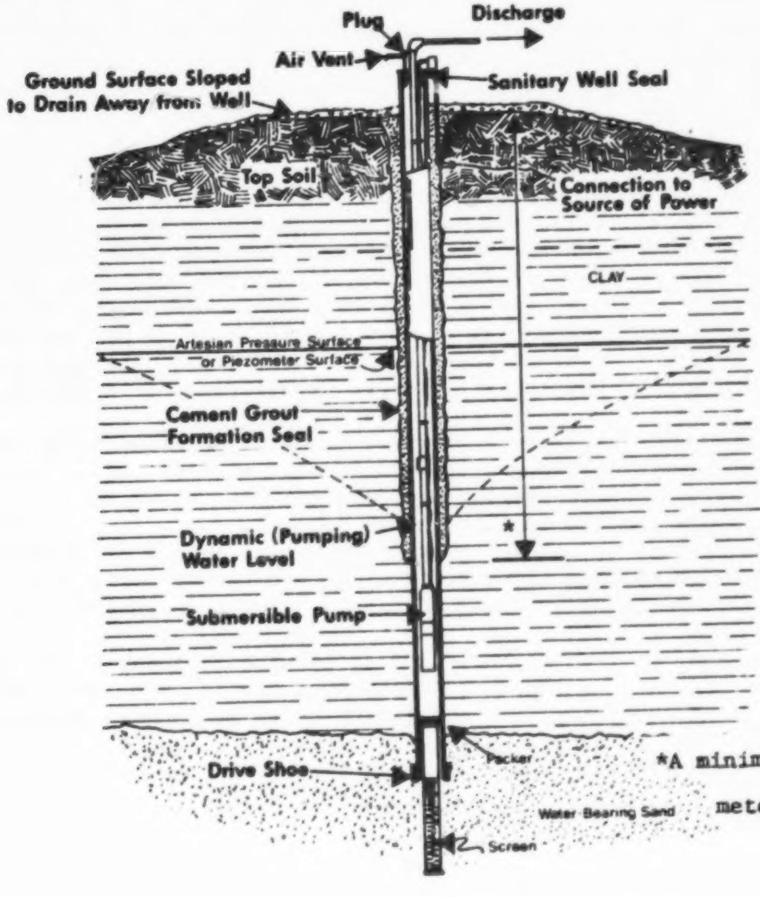
A sanitary survey should be made of any proposed or existing well site, nearby sewage disposal facilities, caves, sinkholes, abandoned borings, or any other possible sources of contamination. Improperly sealed wells should be evaluated to determine their effect on the groundwater quality. Geologic studies should be conducted to locate any fissures or faults overlying the aquifer which also might affect the water quality.

It is of primary importance that contaminated surface water be prevented from entering a well before it has undergone natural purification by ground filtration to the greatest extent possible. The well site should be graded so that surface discharge is diverted away from it. A well casing should be installed to prevent contamination of the well from any strata containing pollution. In addition, a cement grout seal extending from the surface to a depth of at least 3 meters should be constructed around the well casing in stable soil formations, e.g., clay, to prevent surface water from using the construction disturbed space around the casing as a channel. In caving formations such as sand, the construction opening around the casing would tend to be selfsealing, reducing this problem.

Ideally, water supply wells should be developed in formations sufficiently deep to minimize the effects of surface contamination. The minimum depth sufficient for this purpose depends on the soil formations surrounding the well field. The AWWA states that "Experience has indicated that in unconsolidated materials, water obtained from depths of 8 to 9 meters or more is reasonably well protected". In situations such as these, the well casing should extend to at least that depth with the screen being below it. If it is necessary to construct a well at less than the recommended depth in pervious ground, some protection from bacterial contamination of the water supply could be achieved through the application of an impervious layer of material at the ground surface. Such a layer of impervious material (e.g., clay) should be at least 0.61 meters thick and extend for a radius of 15.24 meters from the center of the well.

In drilling a well, it may be necessary to pass through one aquifer to reach a lower one of superior water quality. When this is done, it may be necessary to install a seal between the bore hole and the well casing at a point below the unused aquifer. This will prevent unwanted water from traveling downward and contaminating the desired supply. Various methods are used for sealing off aquifers in this situation: however, the basic principles are the same. The area to be sealed is bored or drilled out to a diameter larger than the final well casing. Cement grout is installed in the annular space between the wall of the bore hole through the unused aquifer, and the final well casing. After the cement has hardened, drilling may continue deeper with additional casing and screen being telescoped through the upper casing, as required.

During well construction, some bacterial contamination by the well will probably occur from the equipment and drilling techniques used. Lengthy pumping will probably eliminate the problem. However, disinfection of the well will provide more rapid results. Chlorine concentration of 50 mg/l in the well casing will be necessary. To achieve maximum decontamination, this solution must come into contact with all components of the well, pumping apparatus and discharge piping.


Plug
Discharge
Air Vent
Ground Surface Sloped to Drain Away from Well
Sanitary Well Seal
Top Soil
Connection to Source of Power
CLAY
Artesian Pressure Surface or Piezometer Surface
Cement Grout Formation Seal
*
Dynamic (Pumping) Water Level
Submersible Pump
Packer
Drive Shoe
Water Bearing Sand
Screen

*A minimum depth of 3 meters of cement grout seal

Figure GW-1 - Drilled Well Showing Sanitary Protective Features

RESERVOIRS

Thermal Stratification

A major chemical-physical activity which can occur in reservoirs is thermal stratification. This action occurs during the spring and summer months when warm air heats the surface waters of the reservoir reducing their density. The layer of water at the surface (epilimnion), usually from 1 - 8 meters in depth, maintains a high DO content and uniform temperature due to wind action. Below this lies a layer (thermocline) from 2 - 7 meters in depth in which the temperature rapidly drops. The bottom layer (hypolimnion) contains the coldest, most dense water with extremely low or nonexistent DO levels. In the fall, cooler air temperatures result in a mixing of the layers resulting in relatively isothermal temperatures throughout the reservoir, (See RES-1).

The high DO levels occurring in the epilimnion will result in the oxidation and subsequent precipitation of dissolved iron and manganese. This situation is often amplified by the fact that the warm waters of the epilimnion are favorable to the growth of algae and microscopic plants which produce carbon dioxide by photosynthesis in addition to taste, odor, and color problems. The carbon dioxide going into solution lowers the pH of the surface waters, creating a condition still more favorable to the formation of iron and manganese precipitates. In the hypolimnion, a stagnation zone develops as the BOD greatly reduces the DO concentration. This anaerobic condition combined with organic matter which has settled to the bottom of the reservoir will result in by-products which will lower the water quality. These by-products include hydrogen sulfide and other organic decomposition products which generate undesirable tastes, odors, and in some cases toxic compounds. In addition, any iron and manganese which has precipitated to the bottom of the reservoir will tend to go back into solution due to the higher pH, further lowering the water quality in the hypolimnion. (See RES-2).

To ensure a constant high level of water quality in a reservoir, the prevention of stratification or the utilization of destratification methods may be necessary. Various researchers have shown that destratification prevents the low quality waters normally found in the hypolimnion from forming as well as preventing normal fall algal blooms. Therefore, the prevention of stratification may reduce taste, odor, color, iron and manganese problems formerly present in reservoir water.

Destratification, or the prevention of stratification, may be accomplished by two basic methods. One method, mechanical pumping, involves the pumping of hypolimnion water to the epilimnion where it becomes reaerated by wind action. The second method uses a land based blower connected to an underwater air diffusion system, usually located in the hypolimnion to provide DO and turbulence. Both systems will destroy the density layers of the reservoir.

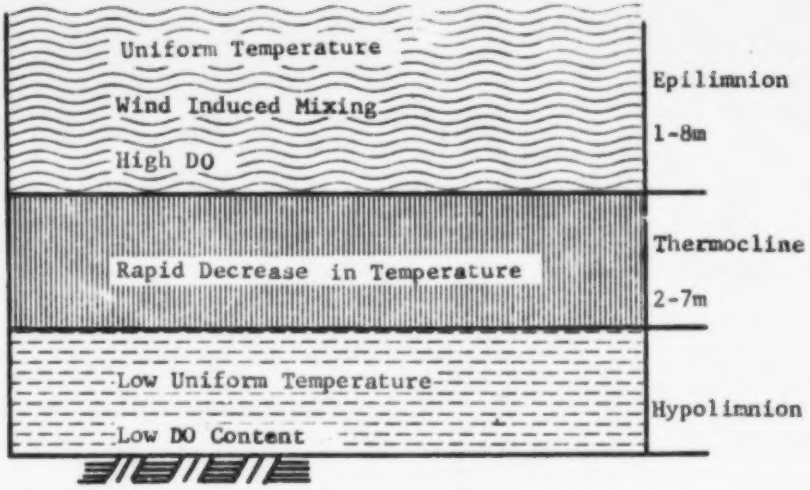

Uniform Temperature
Wind Induced Mixing
High DO
Epilimnion
1-8m
Rapid Decrease in Temperature
Thermocline
2-7m
Low Uniform Temperature
Low DO Content
Hypolimnion

Figure RES-1 - Thermal Stratification
(Ref. 86)

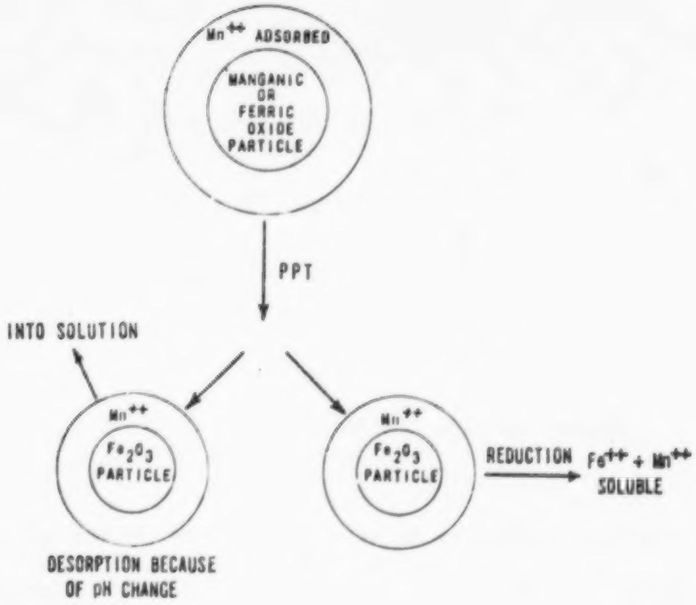
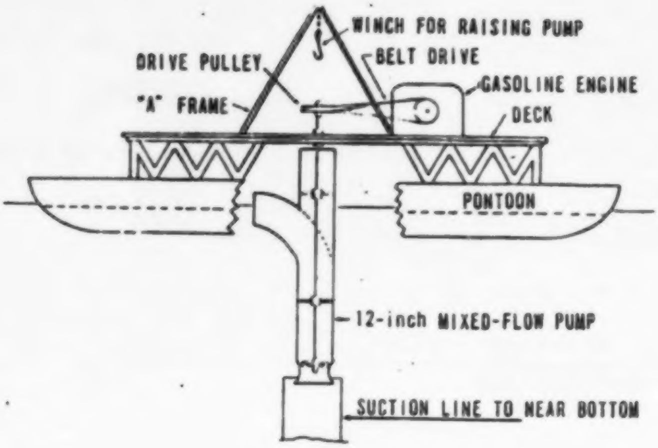
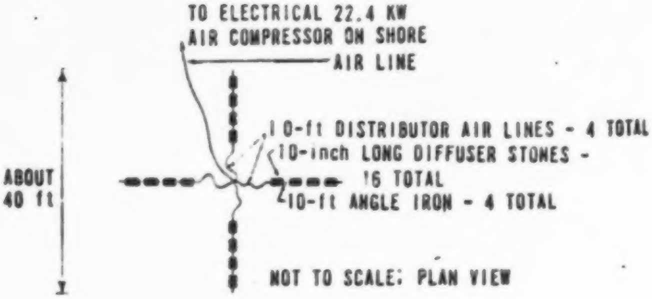

Mn++ ADSORBED
MANGANIC OR FERRIC OXIDE PARTICLE
PPT
INTO SOLUTION
Mn++
Fe2O3 PARTICLE
DESORPTION BECAUSE OF pH CHANGE
Mn++
Fe2O3 PARTICLE
REDUCTION
Fe++ + Mn++ SOLUBLE

Figure RES-2 - Iron and Manganese in a Thermally
Stratified Reservoir
(Ref. 86)


WINCH FOR RAISING PUMP
DRIVE PULLEY
BELT DRIVE
GASOLINE ENGINE
"A" FRAME
DECK
PONTOON
12-inch MIXED-FLOW PUMP
SUCTION LINE TO NEAR BOTTOM

Mechanical Pump System


TO ELECTRICAL 22.4 KW
AIR COMPRESSOR ON SHORE
AIR LINE
10-ft DISTRIBUTOR AIR LINES - 4 TOTAL
10-inch LONG DIFFUSER STONES - 16 TOTAL
10-ft ANGLE IRON - 4 TOTAL
ABOUT 40 ft
NOT TO SCALE; PLAN VIEW

Diffused-Air System

Figure RES-3 - Two Examples of Artificial Destratification Devices

Ideally, a reservoir should be destratified in the spring to prevent the formation of poor quality water, rather that in midsummer to improve poor water quality. This is the case despite the fact of the hydraulic inefficiency of raising cold water at this time of the year and the necessity of occasional remixing during the summer season. Some of the poor hydraulic performance could be overcome by pumping the warm surface water layer down into main water body in the spring. Exact rates of change in the reservoir from the isothermal to the stratified states will have to be determined for each individual reservoir, as reservoir shape, size, and amount of protection will vary. In addition, climatic conditions averaged over previous years will be a major factor in the rate and extent of stratification.

One method of calculating the energy required to destratify a reservoir is to determine its stability. Stability is defined as the amount of energy required to lift the weight of an entire body of water the vertical distance between the centers of gravity of the body of water in a stratified and in an isothermal condition. This measure may also be used to indicate the efficiency of destratification techniques while they are in progress.

Table RES-1 provides data from various destratification studies. The "change in stability" column indicates whether or not the stability index was corrected for natural changes in stability due to climatic effects. The destratification efficiency (DE) is a measure used by researchers to indicate the mechanical performance of artificial destratification devices.

$$DE = \left[\left(\frac{\text{Net Change in Stability from } t_1 \text{ to } t_2}{\text{Total Energy Input from } t_1 \text{ to } t_2}\right) X\ 100\right]$$

Exact engineering analysis and cost data for thermal destratification is not available. A questionnaire sent to approximately 40 reservoir maintenance facilities indicated an extremely wide variety of equipment sizes used and no correlation to effectiveness. The equipment described in this report is the result of initial experimentation only, not engineering analysis.

Table RES-1 - Comparison of Destratification Efficiencies of Various Studies

Lake reference	Dates of mixing	Method	Volume, acre-ft.	Change in stability (uncorrected (U) or corrected (C)), kw-hr	Total energy input, kw-hr	Destratification efficiency-DE[a] (calculated over entire mixing period),%	Total energy input/unit volume/mixing,[a] kw-hr/acre-ft
Test Lake 1	6/2/-6/7,	Diffused-air pump	2,900	27 (C)	1,760	1.5	0.6
	6/21-6/24,			23 (C)	1,680	1.4	0.6
	7/15-7/20,			33 (C)	2,200	1.5	0.7
	8/18-8/23,			16 (C)	2,860	0.6	1.0
	1966					1.2[b]	0.7[b]
						0.5	-
Test Lake 2	(5/16-5/19, 5/20-5/23),	Diffused-air pump	4,600	7 (C)	3,285	0.2	0.7
	6/10-6/15,			24 (C)	2,740	0.9	0.6
	7/1-7/8,			35 (C)	3,740	0.9	0.8
	7/26-8/3,			28 (C)	3,550	0.8	0.8
	9/8-9/13,			8 (C)	2,540	0.3	0.5
	1966					0.6[b]	0.7[b]
						0.2	
Vesuvius Lake[1]	9/3-9/17/64	Mechanical pump	1,260	6.7 (U)	1,862	0.4[c]	1.5
Boltz Lake[2,3]	8/6-9/10/65	Mechanical pump	2,900	28 (C)	14,300	0.2	4.9
King George VI Reservoir[18]	7/13-7/20/66	Mechanical pump	18,375	44.3 (U)	2,000	2.2[c]	0.1
Lake Wohlford[17]	4/18-4/25/62	Diffused-air pump	2,500	14.8 (U)	2,570	0.6[c]	1.0
Wahnback Reservoir[9]	6/9-9/9/64	Diffused-air pump	33,740	400 (U)	104,800	0.4[c]	3.1
Cox Hollow Lake[7]	6/30-7/18/66	Aero-Hydraulics Gun	1,190	7.9 (U)	2,140	0.4[c]	1.8
						0.6 (avg.)	2 (avg.)

[a] These data are intended as a rough guide only and are influenced by many factors: shape of lake, time of year, meterologic conditions (temperature, sunlight, wind) quality requirements, circulation requirements, and so forth.

[b] Average for all mixings in 1966.

[c] These data may be somewhat in error as the change in stability was not corrected for any natural change in stability that may have occurred during the mixing operation.

Control of Algae and Other Microscopic Organisms

The control of algae and other microscopic organisms in reservoirs is often necessary to reduce taste, odor, and turbidity problems. The characteristics of the tastes and odors associated with different organisms may vary widely (Table RES-2). Usually, consumer complaints are registered when the concentrations of odor-producing organisms is above 500 to 1000 in a given plate area of 400 square microns. However, some algae, e.g. Synura, are objectionable at the lowest detectable level.

The use of copper sulfate for the destruction of algae and other microscopic organisms was suggested by More and Kellerman in 1904. Since then, the chemical has become more widely used than any other algicide. The use of chlorine as a supplemental agent has also occured. Chlorine destroys organisms more susceptible to it than to copper; chlorine oxidizes and thus keeps the DO content at more acceptable levels.

The method and kinetics of the destruction of micro-organisms with copper sulfate and chlorine are similar to those of disinfection. However, in the case of copper sulfate the process may require several days for completion. Undesirable side effects following algal control in reservoirs include: a temporary increase in odor, and a rise in the number of saprophytic bacteria which feed on the remains of the dead organisms. This may result in a DO depletion in the reservoir with subsequent fish kills. In addition, the destruction of one algal genus may result in the rapid rise of another. Remedial treatment of the reservoir with chlorine or activated carbon may be necessary. The amounts of copper sulfate and chlorine necessary for algal control are shown in Table RES-2.

The tolerance of fish to copper sulfate lies within the range of concentrations necessary for algal destruction. However, since algae usually thrive in the uppermost layer of reservoir waters, the lethal dose need only be applied to this layer. This will allow the fish to survive in the lower waters of the reservoir. The destruction of algal blooms should not be necessary. Limnologic and microscopic evidence of impending blooms should allow adequate time for prevention.

Small reservoirs can be protected by adding algicides to their intakes. Dry-feed or solution-feed apparatus suited to the chemical to be applied can be used for this purpose. In large reservoirs, a boat may be necessary for application. Copper sulfate crystals are dragged in burlap sacks behind the boat. The solution rate of the crystals is sufficiently slow to make this method effective. Dry-feed, solution-feed, and dusters of the orchard spraying variety have also been employed successfully.

Powdered activated carbon has been applied with some success to the surface of small reservoirs. This action blocks out the sunlight necessary for the growth of some algae. The carbon also acts to eliminate taste and odor from algal sources. It can be added to the reservoir influent, dispersed from bags or ejected onto the surface as a slurry.

Algae	Organism	Trouble	Copper Sulfate, mg/1	Chlorine mg/1
Diatoms	Asterionella, Synedra, Tabellaria	Odor: aromatic to fishy	0.1-0.5	0.5-1.0
	Fragilaria, Navicula	Turbidity	0.1-0.3	....
	Melosira	Turbidity	0.2	2.0
Green	Eudorina,* Pandorina*	Odor: fishy	2-10	....
	Volvox*	Odor: fishy	0.25	0.3-1.0
	Chara, Cladophora	Turbidity, scum	0.1-0.5	....
	Coelastrum, Spirogyra	Turbidity, scum	0.1-0.3	1.0-1.5
Blue-green	Anabeana, Aphanizomenon	Odor: moldy, grassy, vile	0.1-0.5	0.5-1.0
	Clathrocystis, Coelosphaetium	Odor: grassy, vile	0.1-0.3	0.5-1.0
	Oscillatoria	Turbidity	0.2-0.5	1.1
Golden-brown	Dinobryon	Odor: aromatic to fishy	0.2	0.3-1.0
	Mallomonas	Odor: aromatic	0.2-0.5	....
	Synura	Taste: cucumber	0.1-0.3	0.3-1.0
	Uroglenopsis	Odor: fishy. Taste: oily	0.1-0.2	0.3-1.0
Others	Ceratium	Odor: fishy, vile	0.2-0.3	0.3-1.0
	Glenodinium	Odor: fishy	0.2-0.5	....
	Peridinium	Odor: fishy	0.5-2.0	....
	Cryptomonas	Odor: aromatic	0.2-0.5	....

* These organisms are classified also as flagellate protozoa.

Table RES-2 - Concentration of Copper and Chlorine Required to Kill Algae

SECTION IV

WATER TREATMENT PROCESSES AND ASSOCIATED COSTS

This section is primarily concerned with the development of technical and cost data for each of the treatment processes covered in this monograph. The cost data are presented in sufficient detail that comparative planning estimates of alternative treatment schemes can be made; but it should be noted that the data have been developed from several sources of information, including published data, private files, actual constructed facilities, and from information gleaned from equipment manufacturers and suppliers. Consequently, the data that is contained herein, while current and of sufficient accuracy for planning purposes, should not be used as the basis for preparing bid documents for construction. More detailed investigation is mandatory prior to final system design.

When using the cost data care must be exercised in identifying the specific components included in a single cost curve. For example, in some instances, building costs are given as a single item, since they constitute a relatively large portion of the overall cost. On the other hand, building costs are included with capital cost for treatment processes where the building cost is rather insignificant.

It is also important for the planner to remember that when several treatment processes are combined, the resultant plant costs will be somewhat less than the sum of the costs for each process. This cost reduction is the result of savings which accrue from reduced land requirements, common housing of process equipment and other economies of scale. It is difficult however, to estimate what the cost reduction for combined processes will be and judgment must be used in each specific case. As a general rule, the greater the number of treatment processes the larger the cost reduction; and the cost reduction will be more significant in very large capacity treatment plants.

Local information available to the planner can be utilized in cost estimates. This includes costs of land, electric power, chemicals, and other information. For example, some chemical cost curves are based on a sulfuric acid cost of $40 per U.S. Ton. If the local price is $30 per U.S. Ton, then the cost determined from the curve can be multiplied by 3/4 or 0.75 to obtain a reasonable local cost. In addition, cost indices are used to provide a baseline for projecting costs, and for estimating escalation due to inflation. The indices used in this report are national indices. They are, however, frequently available for major U.S. cities or on a regional basis. These city or regional indices may be substituted, if desired.

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The cost indexes used in this report are:

i. Engineering News-Record-Building Cost Index. (ENR BCI) This index was introduced in 1938 in order to measure the effects of wage and materials price trends. The Building Cost Index has skilled labor and materials components and is used for cost estimates for buildings, site development, utilities, and general civil construction. The national average ENR BCI appears weekly in the "Scoreboard" section of Engineering News-Record Magazine. City-by-city Building Cost Indexes for 22 U.S. cities appear monthly in the second ENR issue of the month. The ENR BCI used in this report for all appropriate curves is 1154 for October 1973. ENR occasionally forecasts the BCI in articles.

ii. Handy-Whitman Index. This index pertains specifically to large water treatment plants. The index used in this report is an average for the six geographical regions shown in the Handy-Whitman Manual - 290.4 for July 1973. The Handy-Whitman Index is published every six months, January and July, and the index value for July 1973 is applicable to the October 1973 curves.

iii Bureau of Labor Statistics - Labor Costs Index. The index used in this report is for personnel in Standard Industrial Category (SIC) 494.7, or Water, Steam and Sanitary Systems Non-Supervisory workers. The base BLS Labor Cost Index for July 1973 is 4.18, the index has been modified to 6.25 to include overhead and payroll expense (30% overhead, 15% payroll Expense). This information can be obtained from Employment and Earnings Statistics on the Labor Force, published monthly by the U.S. Department of Labor, Bureau of Labor Statistics.

iv. U.S. Bureau of Labor Statistics - Chemical Index. The index used in this report to indicate chemical price trends is 104.3, which is the September 1973 Industrial Chemicals Index, (Code 061). This information can be obtained from the Wholesale Prices and Price Indexes Data, published monthly by the U.S. Department of Labor, Bureau of Labor Statistics.

This section is organized into three parts. The first part, immediately following the introduction, contains brief technical descriptions of the treatment method followed by the cost data. The second part deals with miscellaneous treatments and with chemicals used in water treatment, giving representative costs and physical and chemical descriptions. Unit Cost curves for each process have been developed and presented in Section VII.

AERATION

Aeration is a technique used in water treatment which has not had a particularly widespread application. Of the many municipal treatment plants in the United States, only about ten percent use aeration.

Aeration is used to produce two opposing end results in the treated water:

i. The removal of volatile organic materials and fairly soluble gases, such as carbon dioxide and hydrogen sulfide. Also, the air or oxygen stream effectively strips miscellaneous entrained but insoluble materials such as methane.

ii. The addition of oxygen to the water for the oxidation of iron and manganese, hydrogen sulfide, and some organic materials.

Carbon dioxide is used in lieu of an air stream when recarbonation is required for the neutralization of excess alkalinity. Although the device used is a form of aeration column, aeration more generally applies to the treatment of water with an air and/or oxygen stream.

Aeration is efficient in removing odor and taste causing substances except for some organics. The material(s) causing the problems must have a high volatility, a situation which does not generally occur. Several days storage after aggresive aeration may oxidize some odor-causing organics to non-odorous forms, but the treatment is unpredictable and therefore rarely used.

Aeration is most sucessfully used in the removal of carbon dioxide, the oxidation of iron and manganese, and the removal of the odors caused by hydrogen sulfide. Aeration will usually cause the co-precipitation of iron and manganese without additional treatment. However, if colloidal organic material is present, complexes may be formed which do not flocculate sufficiently for satisfactory settlement. In such cases, additional treatment may be necessary.

There are two principle types of aerating equipment, the cascade type, and the diffused-air type. For either type, power is necessary and is required in approximately equal amounts.

The mass-transfer of oxygen from gas (air stream) to liquid (water) occurs at the gas-liquid interface. Because these mass transfer rates are generally low, the residence time necessary for oxygen absorption or the area of the interface of absorption, must be increased. Obviously, increasing the residence time affects the physical size of the equipment and thus the cost. Increasing the surface area available for absorption and constantly changing the absorbing surface by creating turbulent conditions does not increase the size of the equipment, but merely makes the design of the internals [1] of great importance.

---

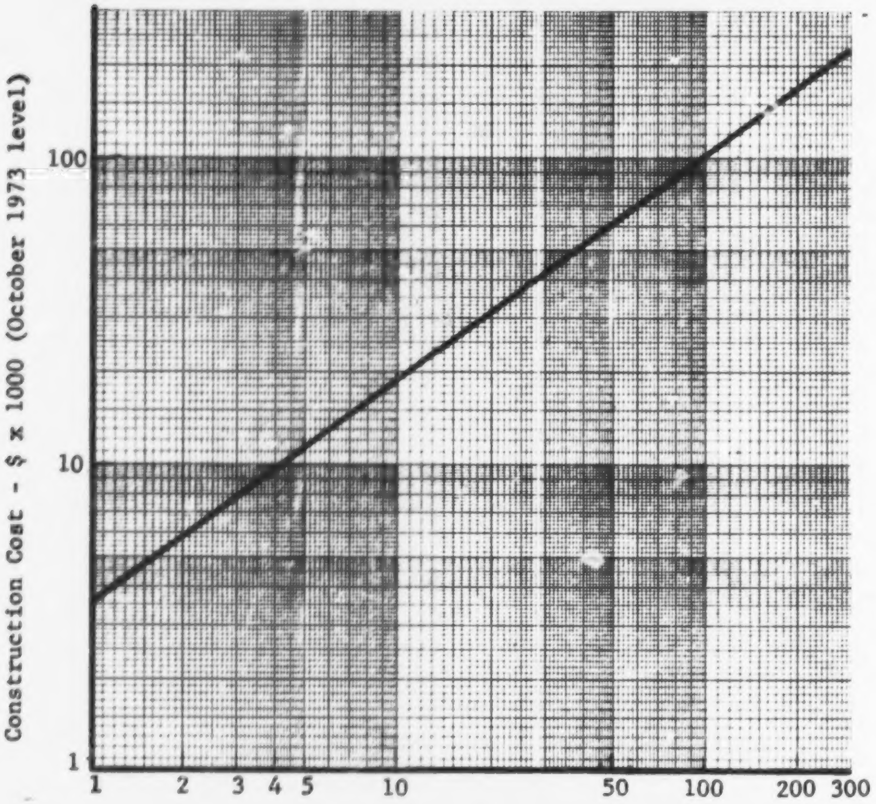
1. Refers to internal construction of equipment.

Cascade aerators rely on the movement of the water under the force of gravity over a series of obstacles to create the required turbulence. The water is usually pumped to create the head, and this is a measurable cost. The devices used to promote the necessary turbulence may be any one of a number of designs. Weir trays, slat packings, Raschig rings, Berl saddles and sieve or slotted trays are all used. When sieve or slotted trays are employed, they are frequently packed with a coarse media such as coke or crushed stone. This technique is most successful and ensures a high degree of turbulence

Diffused air equipment provides a longer aeration time than cascade types because the upward motion of an air bubble is slower than a falling water drop. However, the turbulence is less, and this reduces the mass-transfer capability. Power requirements for air compression are approximately the same as the power requirement necessary to produce the head for cascade types, but initial cost may be higher. Selection of diffused-air over cascade becomes a matter of personal preference.

The results of removal of odor through aeration have been reported in the literature as being unpredictable. The upper limit has been reported in actual water works practice as 51 percent removal of threshold odor caused by algae. Almost complete removal of odor caused by hydrogen sulfide is possible with properly designed equipment and sufficient air flow. Similar high values of removal can be expected for iron and manganese, but provision must be made for collecting and removing the precipitant.

ENR BCI 1154

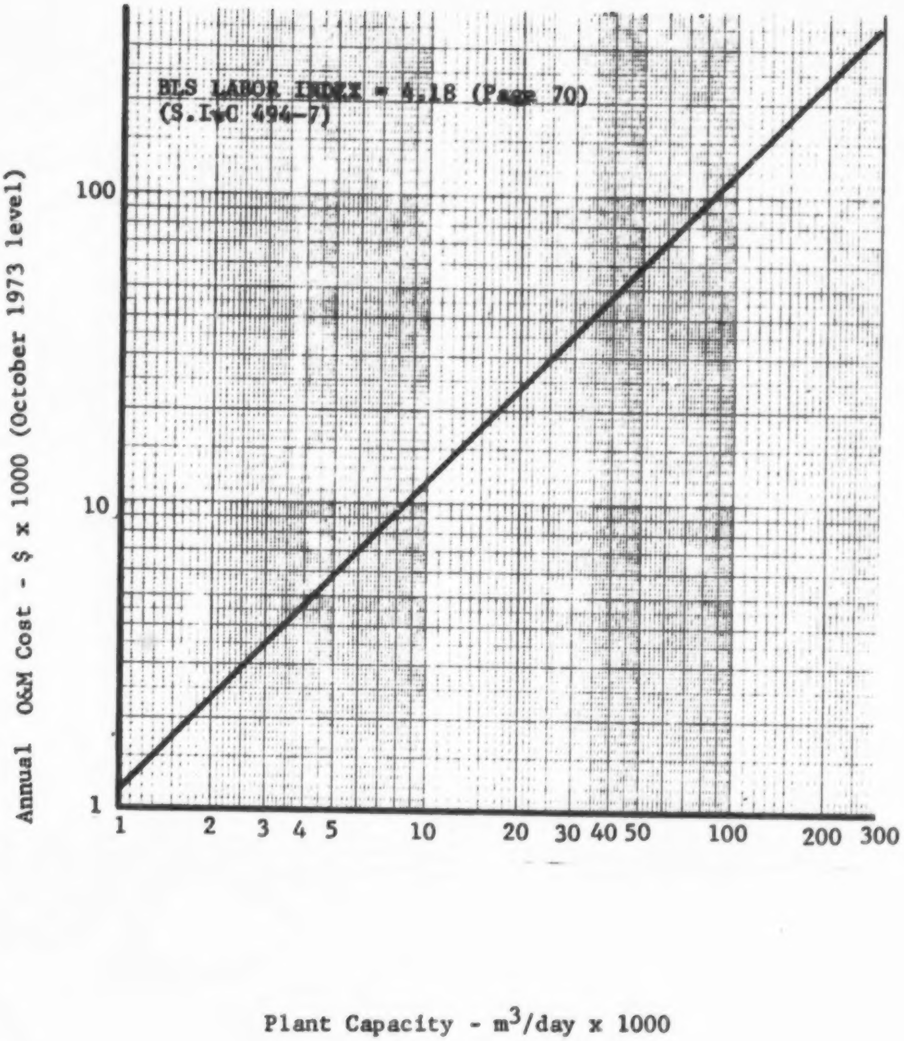


Plant Capacity m^3/day x 1000

Cost Includes	Cost Does Not Include
Column with internals	Land (negligible)
Blower	Owner's General Expense
Foundations	Interest during construction
Piping and Controls	
Enclosure	
Design engineering	
Construction overhead	

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure A-1 - Aeration Equipment Construction Cost



Costs Include

O&M labor
Payroll expenses
Overhead
Regular Maintenance Supplies
  and Materials
Curve uses Modified Index 6.25

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure A-2 - Aerator O&M Costs

SEDIMENTATION

Sedimentation is the settling under gravity of particles suspended in a body of water. While an excellent method of removing suspended solids of fairly large size, the time required for the smaller particles to settle is extremely long. Table S-1 shows the relative settling times for particles of decreasing size.

Table S-1

Relative Settling Times of Various Sized Spheres

Typical Material	Particle Diameter	Cross-sectional Area	Time to Settle 1 ft.
Gravel	10 mm	78.55 sq. mm	0.3 sec
Coarse Sand	1 mm	0.786 sq. mm	3 sec
Fine Sand	0.1 mm	7.855×10^{-3} sq. mm	38 sec
Silt	0.01 mm	7.855×10^{-5} sq. mm	33 min
Bacteria	1×10^{-3} mm	7.855×10^{-7} sq. mm	55 hr
Colloidal	1×10^{-5} mm	7.855×10^{-11} sq. mm	6.3 yrs
Colloidal	1×10^{-6} mm	7.855×10^{-13} sq. mm	63 yrs

From this data, it is obvious that the removal of suspended solids with a diameter of less than 0.01 millimeters would take an excessively long period of time to settle. Because of this fact, sedimentation is not a method of suspended solids removal which is in general use, except as pre-treatment for the protection of pumps and piping and to prevent overloading in subsequent operations.

The settling velocity of a particle in water can be calculated from Newton's formula:

$$V^{2-n} = \frac{4d^{1+n} \quad g\ (Ps-Pe)}{3\ CPe}$$

where V = terminal velocity in cm/sec
d = particle diameter in cm
g = acceleration due to gravity = 981 cm/sec^2
Ps and Pe = specific gravity of the particle and the water respectively
C = drag coefficient related to Reynolds No. by the expression $C = a\ Re^{-n}$
a and n = coefficients

The following table gives values of a,n, and C for various ranges of Reynolds no.

Table S-2 Values of a, n, and C

Re	a	n	C	Formula
$10^{-4} < Re < 1$	24	1	$24/Re$	Stokes
$1 < Re < 10^3$	18.5	0.6	$18.5\ Re^{0.1}$	Allen
$10^3 < Re < 4 \times 10^5$	0.44	0	0.44	Newton

The formula applies to a spherical particle only. Since the suspended solids in water are not generally spherical, a correction factor is needed to modify the drag coefficient C. This factor is called sphericity Ψ, and some typical values are shown below.

Values of Ψ

Sand	2	Graphite flakes	22
Coal	2-25	Mica	170
Talc	3-25	Gypsum	4

Therefore, by using this factor, $C' = C\Psi$, or $C' = \Psi a Re^{-n}$, and C' is substituted in Newton's formula.

If the average particle size and type are known, therefore, the average settling velocity can be calculated. It is also possible to compute the dimensions of a vessel which will remove the suspended solids or a predetermined fraction thereof, by sedimentation.

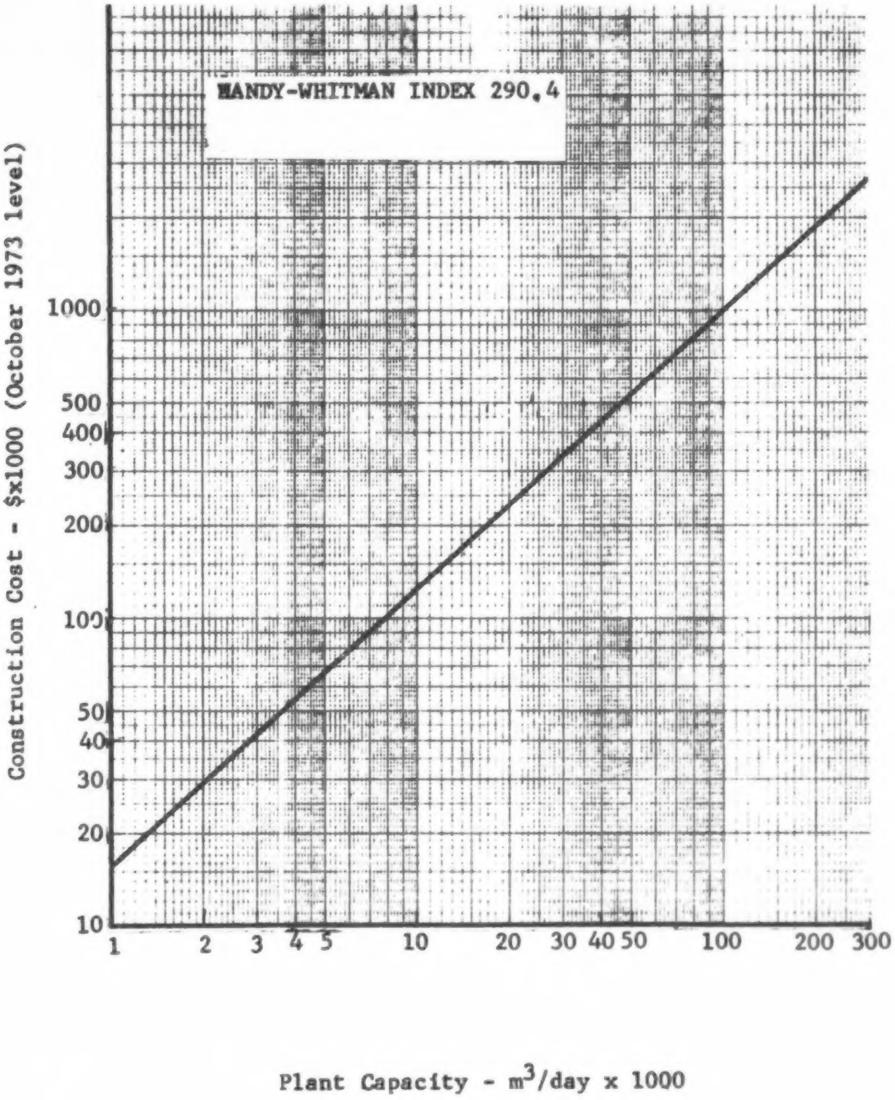
In practice, the data on the following page may be used for free-falling sand particles with a density of 2-65.

Table S-3 Settling Velocity for Various Particle Sizes

d cm	0-005	0-010	0-020	0-030	0-040	0-050	0-10	0-20	0-30	0-50	1-100
V_1 cm/s	0-2	0-7	2-3	4-0	5-6	7-2	15	27	35	47	74
V_2 cm/s	0	0-5	1-7	3-0	4-0	5-0	11	21	26	33	
V_3 cm/s	0	0	1-6	3-0	4-5	6-0	13	25	33	45	65
V_c cm/s	15	20	27	32	38	42	60	83	100	130	190

where:

d = diameter of the sand particle,
V_1 = settling speed, for fluid with negligible horizontal velocity,
V_2 = settling speed, for fluid with a horizontal velocity equal to V_c,
V_3 = settling speed, for fluid with a horizontal velocity equal to 0-30 m/s,
V_c = critical horizontal fluid speed at which deposited sand particle is entrained.



Cost includes:

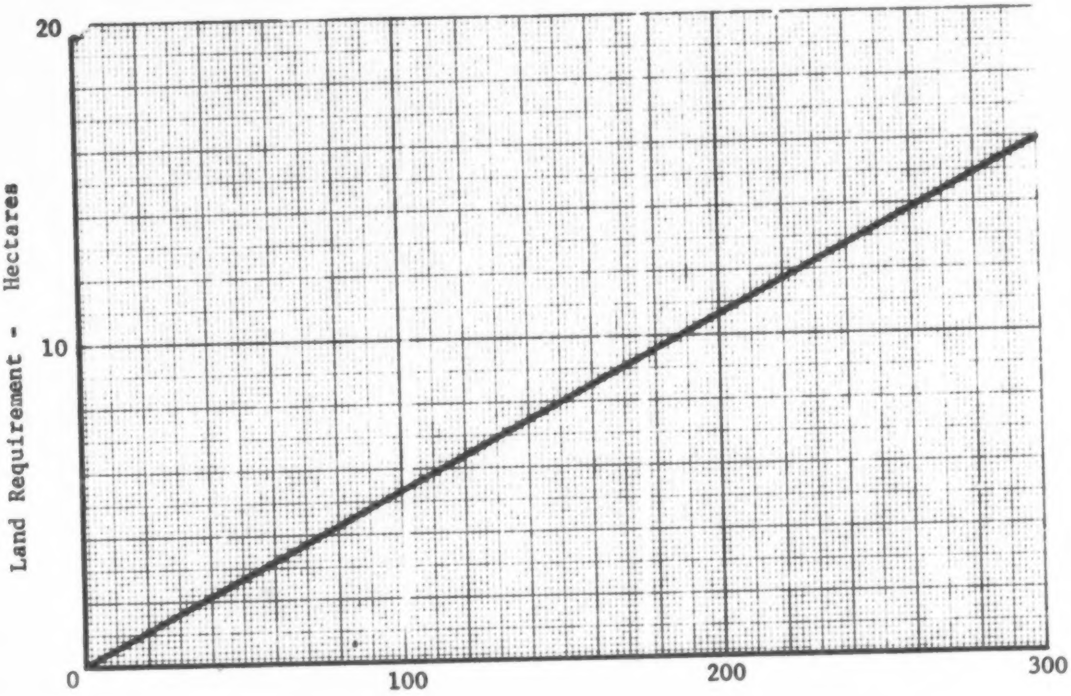
Piping and sludge removal equipment
Controls
Concrete Construction
Design & Specifications
Construction overhead

Cost does not include:

Interest during construction
Owner General expense
Land Costs
Sludge disposal costs. (must be determined on individual profit basis)

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure S-1 - Sedimentation Plant Construction Cost

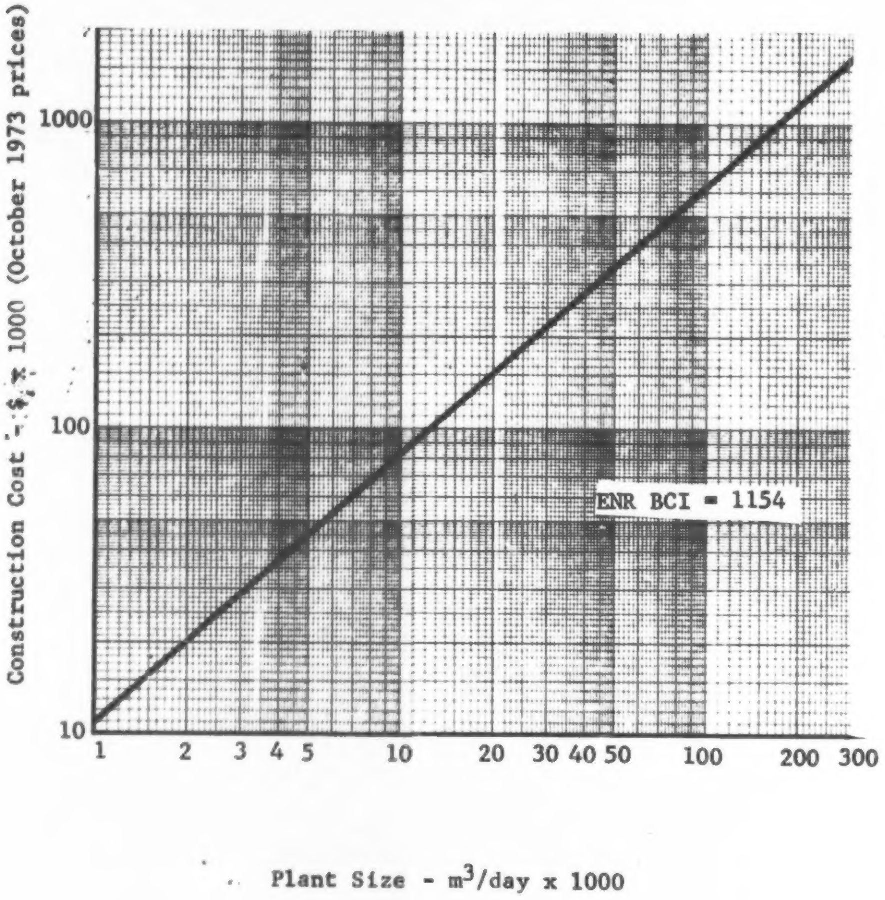


Plant Capacity - m^3/day x 1000

Note: if plant capacity is less than 5,000 m^3/day use 0.1 hectare.

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

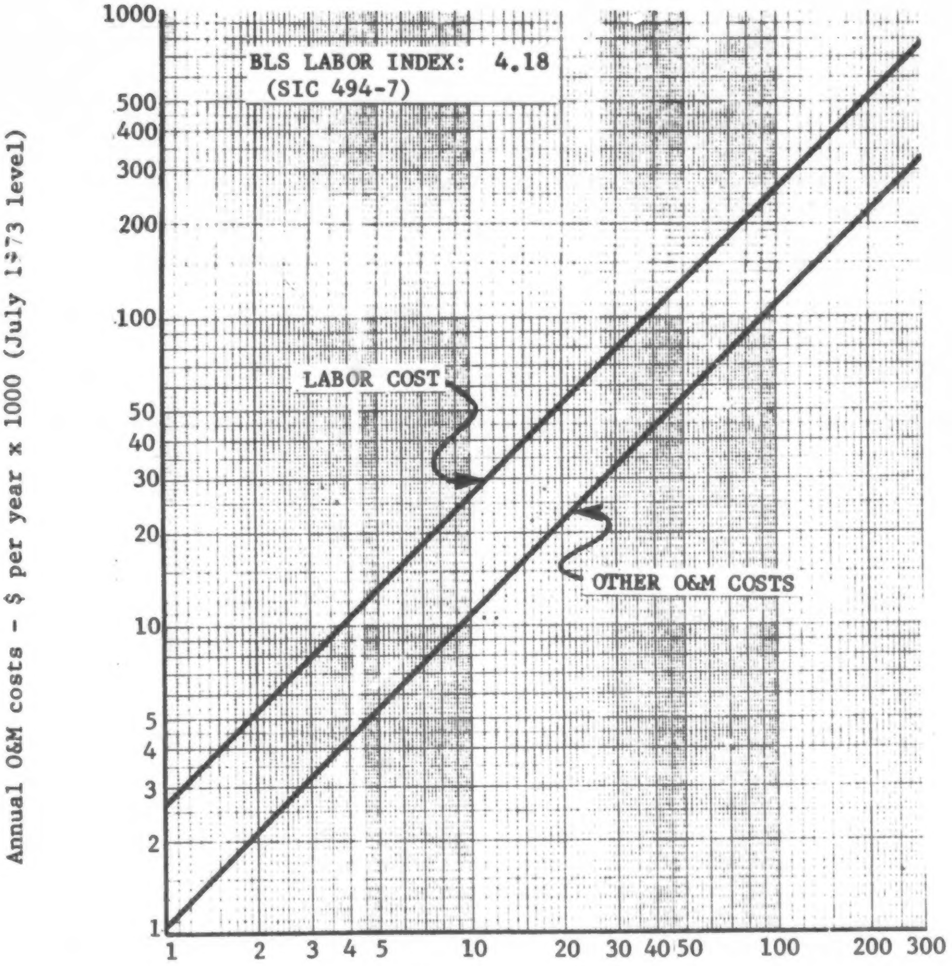
Figure S-2 - Land Requirement for Sedimentation Plant



Includes	Excludes
Grubbing, clearing and grading	Owner's general expense
Roads	Interest during construction
Fences and gates	Land cost
Utilities	
Service Buildings	
Design and Specifications	
Construction Supervision	

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure S-3 - Site Developmemt Costs-Sedimentation Plant



Plant Capacity - m^3/day x 1000

Cost Include	Does Not Include
Labor Payroll	Major repair items
Payroll overhead and extras	Labor from major repair
Regular maintenance items	
Consumable supplies	

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure S-4 - Operating and Maintenance Cost Sedimentation Plant

COAGULATION

As has already been stated, because of the potentially long time periods involved and the corresponding large land areas required for sedimentation basins to accomplish the unaided settling of smaller particles, the process is usually accelerated in practice by the use of the technique known as coagulation.

Coagulation consists of introducing into the water a substance which:

i. will discharge the generally electro-negative colloids present,

ii. give rise to a precipitate which has a rapid rate of settlement.

The primary substances or coagulants used in this treatment are described below:

1. Aluminum sulfate + calcium carbonate

   $Al_2(SO_4)_3 + 3\ Ca(HCO_3)_2 = 3\ CaSO_4 + 2\ Al(OH)_3 + 6\ CO_2$
   Dose: 15 to 100 g/m^3 of $Al_2(SO_4)_3 \cdot 18\ H_2O$ (commercial) according to the turbidity of the water.

2. Aluminum sulfate + sodium aluminate:

   $6NaAlO_2 + Al_4(SO_4)_3 \cdot 18\ H_2O = 8Al(OH)_3 + 3Na_2SO_4 + 6H_2O$
   Dose: The weight of commercial sodium aluminate required is 75% of the weight of aluminum sulfate (commercial) for an equimolecular reaction. The dose of sodium aluminate may, however, be much less, in which case the reagent serves only to initiate the coagulation of the aluminum sulfate.

3. Aluminum chloride (used under exceptional circumstances only):

   $2\ AlCl_3 + 3\ Ca(HCO_3)_2 = 2\ Al(OH)_3 + 3\ CaCl_2 + 6\ CO_2$
   Dose: 12 to 40 g/m^3 of $AlCl3 \cdot 6H2O$ (commercial) according to the turbidity of the water.

4. Aluminum sulfate + hydrated lime:

   $Al_2(SO_4)_3 + 3\ Ca(OH)_2 = 3\ CaSO_4 + 2\ Al(OH)_3$
   Dose: One part of $Ca(OH)_2$ (lime) to three parts of $Al_2(SO_4)_3 \cdot 18\ H_2O$ (commercial)

5. Ferric sulfate:

$$Fe_2(SO_4)_3 + 3\ Ca(HCO_3)_2 = 2\ Fe(OH)_3 + 3\ CaSO_4 + 6\ CO_2$$

Dose: 10 to 50 g/m^3 of $Fe_2(SO_4)_3 \cdot 9\ H_2O$ (commercial) according to the turbidity of the water.

6. Ferric sulfate + hydrated lime:

$$Fe_2(SO)_3 + 3\ Ca(OH)_2 = 2\ Fe(OH)_3 + 3\ CaSO_4$$

Dose: The requirement of hydrated lime as $Ca(OH)_2$ is 40% of the quantity of iron sulfate $Fe_2(SO_4)_3 \cdot 9\ H_2O$.

7. Ferrous sulfate:

$$FeSO_4 + Ca(HCO_3)_2 = Fe(OH)_2 + CaSO_4 + 2\ CO_2$$

Dose: 5 to 25 g/m^3 of $FeSO_4 \cdot 7\ H_2O$ (commercial) according to the turbidity of the water.

In aerated waters, the ferrous hydroxide oxidizes and becomes ferric hydroxide:

$$4\ Fe(OH)_2 + O_2 + 2H_2O = 4\ Fe(OH)_3.$$

8. Ferrous sulfate + hydrated lime:

$$FeSO_4 + Ca(OH)_2 = Fe(OH)_2 + CaSO_4$$

Dose: The requirement of $Ca(OH)_2$ (hydrated lime) is 26% of the quantity of $FeSO_4 \cdot 7\ H_2O$.

9. Ferrous sulfate + chlorine

$$2\ FeSO_4 + 3\ Ca(HCO_3)_2 + Cl_2 = 2\ Fe(OH)_3 + 2\ CaSO_4 + CaCl_2 + 6\ CO_2$$

Dose: The requirement of chlorine is 12% of the quantity of $FeSO_4 \cdot 7\ H_2O$.

The most commonly used coagulant is $Al_2(SO_4)_3 \cdot 18\ H_2O$, which is known as filter alum. The amount of hydrolysis which occurs when filter alum is introduced to the water is a function of the pH of the water. This is demonstrated by Figure C-1 which shows the variation in alum dosage required for changing pH values.

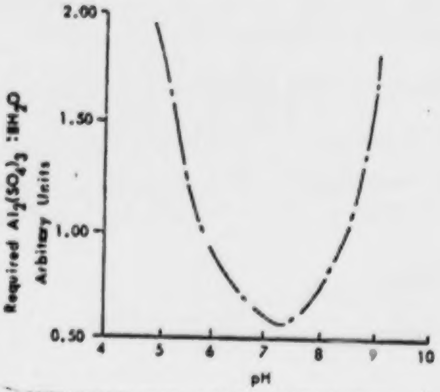


Figure C-1 - The effect of pH on alum dosage for optimum coagulation

Since aluminum and iron sulfates are acidic, they are often used in conjunction with a base such as hydrated lime. Caustic soda can also be used, but is more expensive.

For the most effective use of iron salts as coagulants, the pH range is either 3.5 to 5.5 or above 9.0, either very acidic or very alkaline conditions.[1] Since these pH ranges are not particularly common in the United States as far as municipal water supplies are concerned, iron salts are not generally used for coagulation. Minor pH adjustments can be made to enable filter alum to be used.

The optimum pH and dose of coagulant to be used for a specific water to be treated is determined by the use of one of the two most common methods, the zeta potential method and the jar test method. Althought the jar test method is the established technique, measurement of zeta potential is rapidly gaining wide acceptance.

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[1] If pH cannot be adjusted, iron salts must be used.

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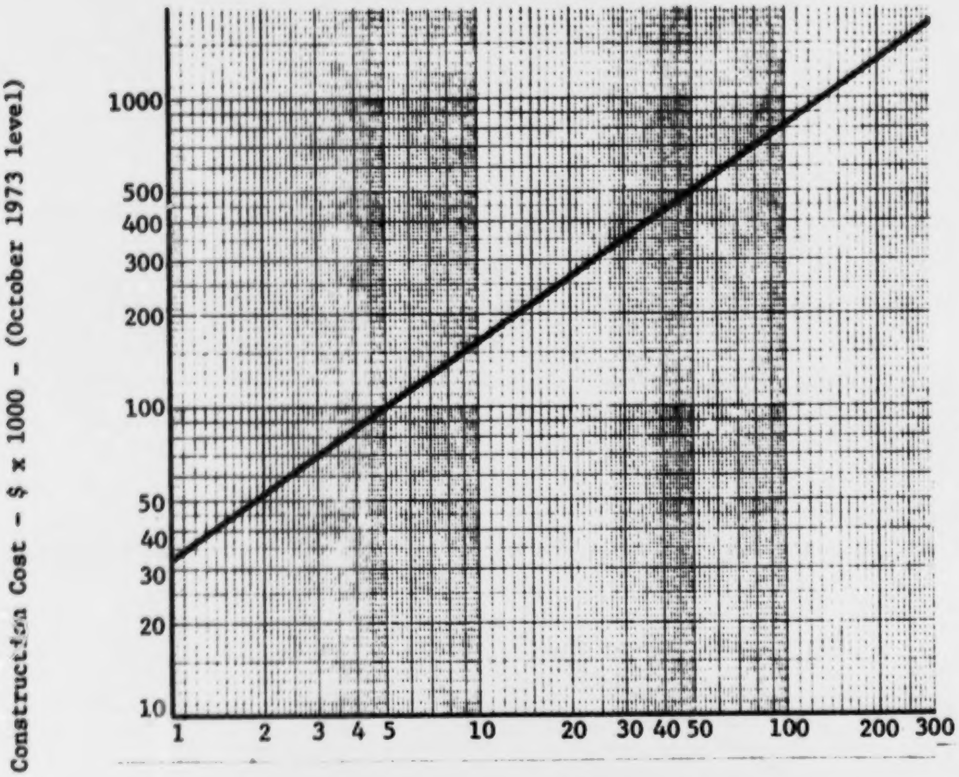

Cost Includes

Piping and Controls
Equipment
Foundations
Flash mixer
Design and Specifications
Construction overhead

Cost Does Not Include

Land cost
Site development
Owner's General Expense
Interest during construction

Source - Environmental Planning & Engineering Division,
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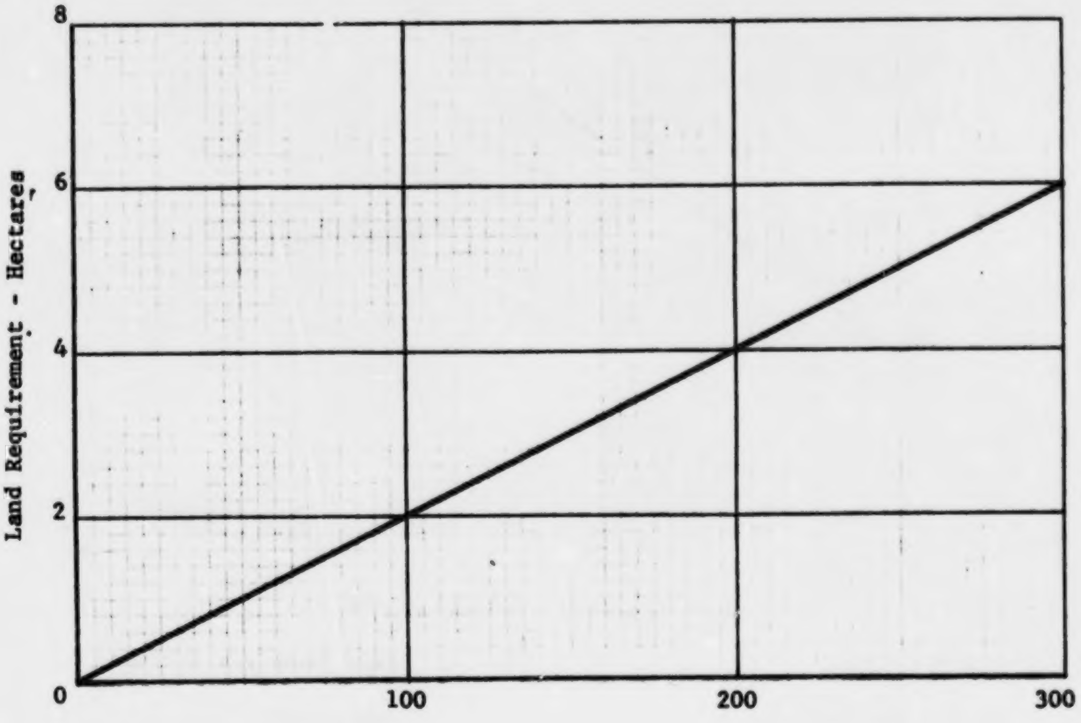
Figure C-2 - Construction Cost for Coagulation Equipment

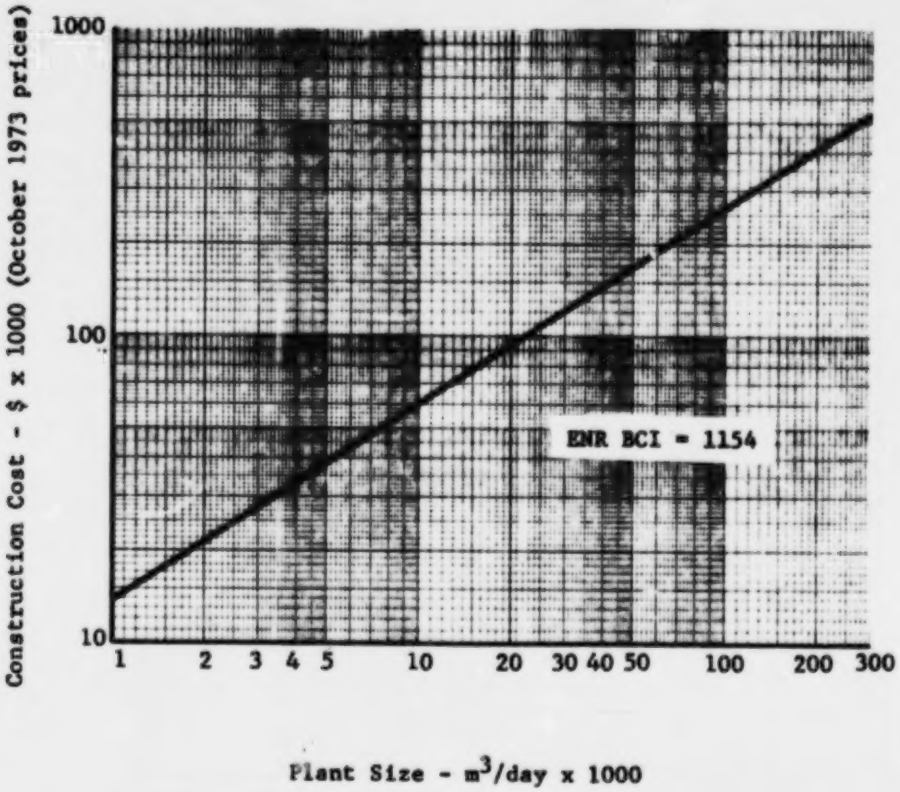


Plant Capacity - m^3/day x 1000

If plant capacity less than 5,000 m^3/day use 0.1 hectare. Source EPA.

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

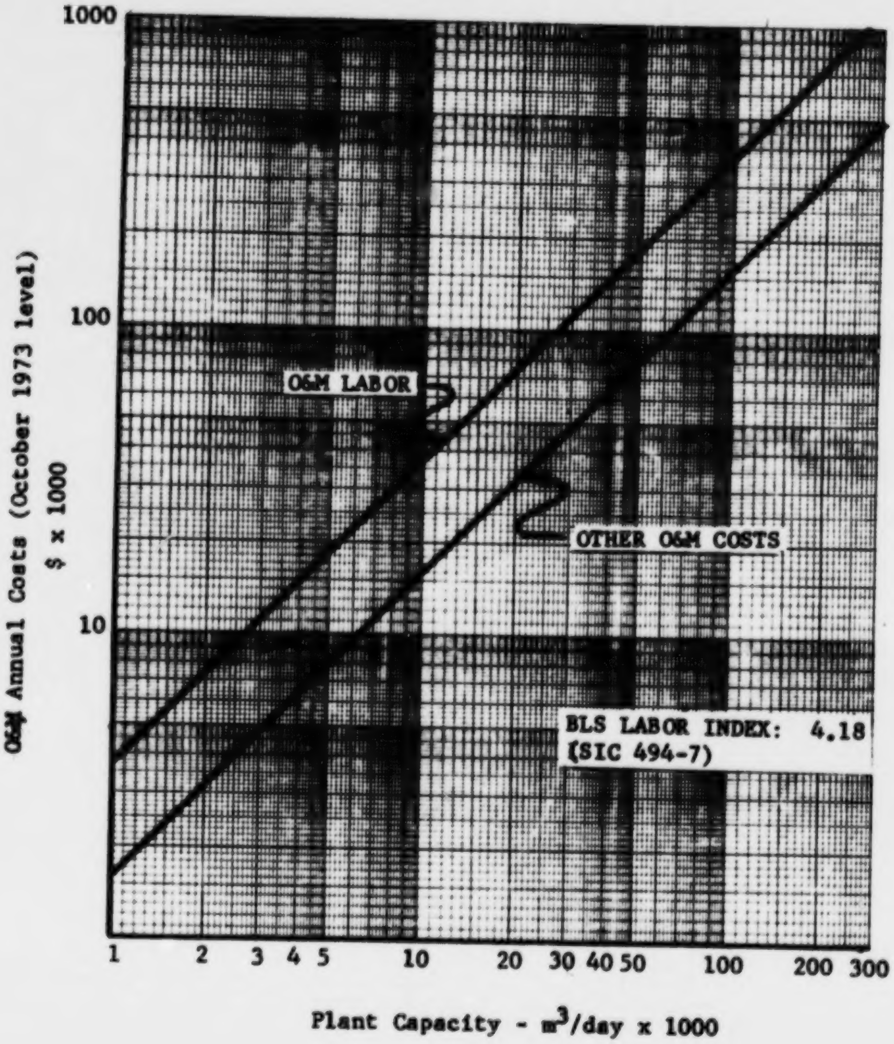
Figure C-3 - Land Requirement for Coagulation



Includes	Excludes
Grubbing, clearing and grading	Owner's general expense
Roads	Interest during construction
Fences and gates	Land cost
Utilities	
Service Buildings	
Design and Specifications	
Construction Supervision	

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure C-4 - Site Development Costs for Coagulation



Cost include	Does not include
Labor payroll	Major repair items
Payroll overheads and extras	Labor for major repair
Regular maintenance items	
Consumable supplies	

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure C-5 - Operating and Maintenance Costs Coagulation Plant

COAGULATION AND SEDIMENTATION

The basic coagulation technique in conjunction with sedimentation is used primarily for the removal of turbidity and the partial removal of color from surface water supplies. Coagulation may also be used, however, for the partial or complete removal of other contaminants under consideration in this document. The chemical requirements and effectiveness of the method in a variety of situations are delineated in the following paragraphs.

a. Color

The removal or reduction of color in the coagulation process is generally accomplished with the use of aluminum sulfate as the coagulant. Clay or activated silica is added as a coagulant aid, clay being used when the natural turbidity of the water is low.

b. Turbidity

Turbidity in water is almost totally removed by coagulation and settling followed by filtration. The dosage of coagulant and coagulant aid or polyelectrolyte to be used must be determined by the jar test or zeta potential method, as well as the determination of the optimum pH for coagulation. Of extreme importance in the removal of turbidity is the formation of a strong, heavy floc, which settles easily and does not disintegrate. If the colloidal turbidity does not flocculate correctly, it passes through the settling stage, and through the filters.

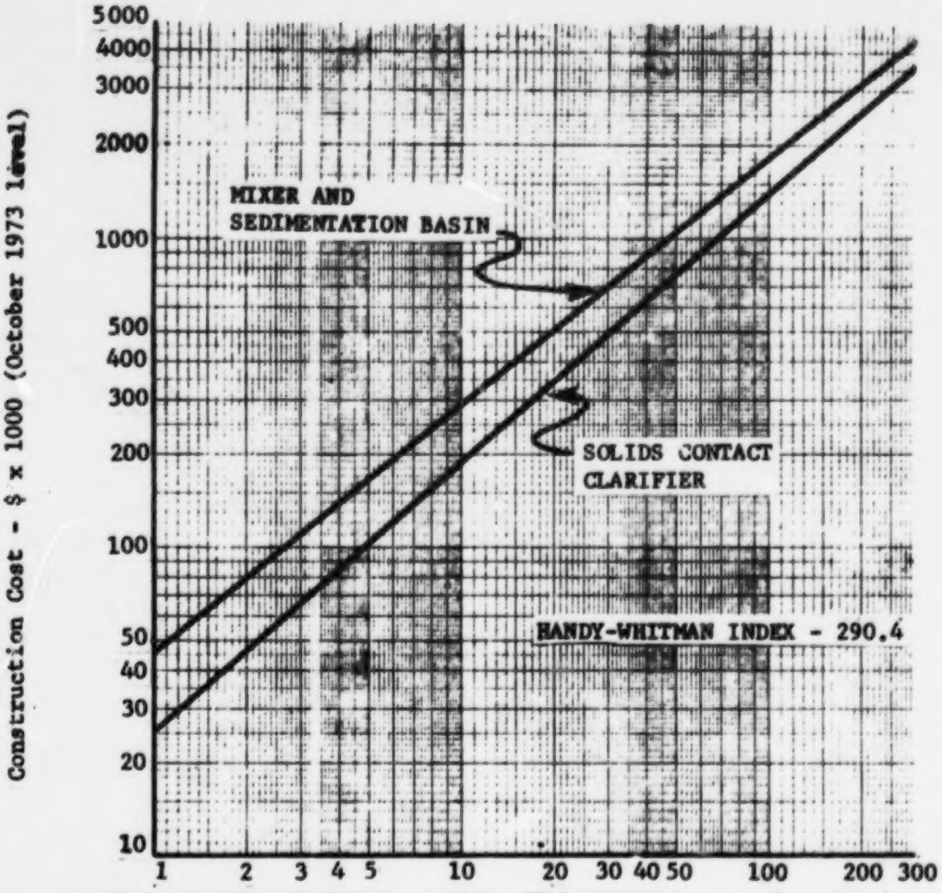
c. Radioactivity

The use of coagulation and settling techiques have been experimented with extensively over the past twenty years. In general, it can be said that the operation is not particularly successful for the radioactive contaminants under consideration in this monograph. EPA sponsored literature searches have accumulated a large amount of data on the decontamination of highly active wastes, primarily from research and power plant operations. There is a paucity of information concerning low level wastes, as are being considered here. Most information shows removal in the order of 30% to 60%, except for some very complex custom-designed systems.

Coagulation and sedimentation can be accomplished by means of flash mixer and sedimentation basins, or by means of solids-contact equipment (also known as clarifiers). In both cases, it is generally required that filtration follow sedimentation.

Cost of Coagulation and Sedimentation System

Cost data for this treatment method are shown in Figures CS-1 through CS-4. There is a difference in cost between "combined" coagulation and sedimentation, and the sum of the cost for the individual processes. This is due primarily to savings in piping, concrete work, site development, engineering and construction overhead. On each curve for solids contact plants below 20,000 m^3/day use 5 hectares, and for sedimentation basins below 10,000 m^3/day use 5 hectares.

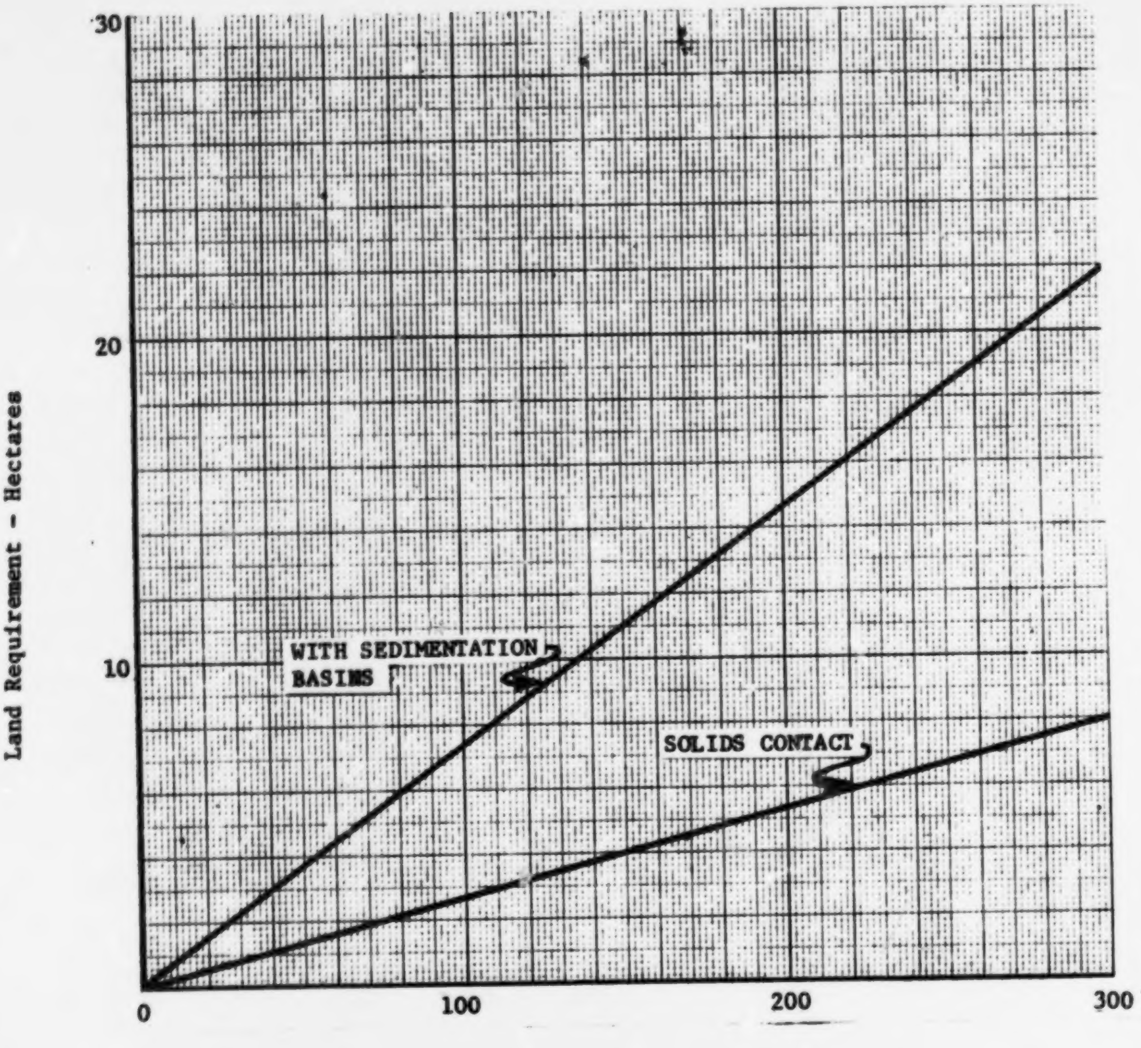


Plant Capacity - m^3/day x 1000

Cost include	does not include
Piping and controls	Land cost
Civil construction	Site development
Mechanical Equipment	Owner's general expense
Design and Specifications	Interest during Construction
Construction overhead.	

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

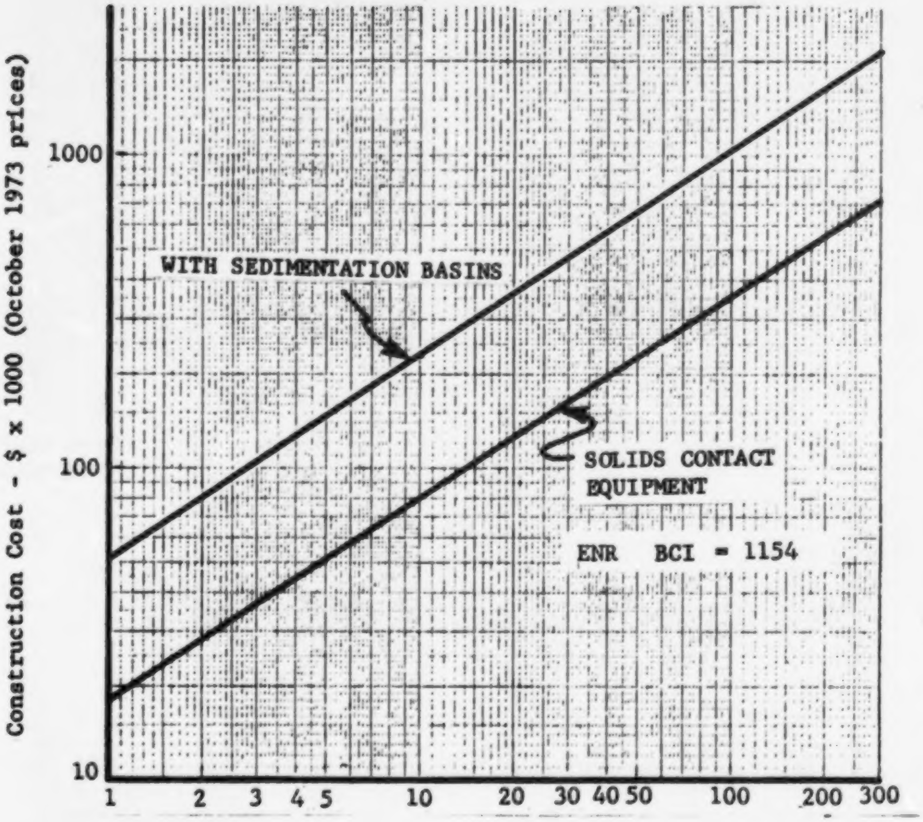
Figure CS-1 - Construction Cost for Coagulation and Sedimentation Systems



Minimum land requirement is .1 hectare

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure CS-2 - Land Requirement for Coagulation and Sedimentation

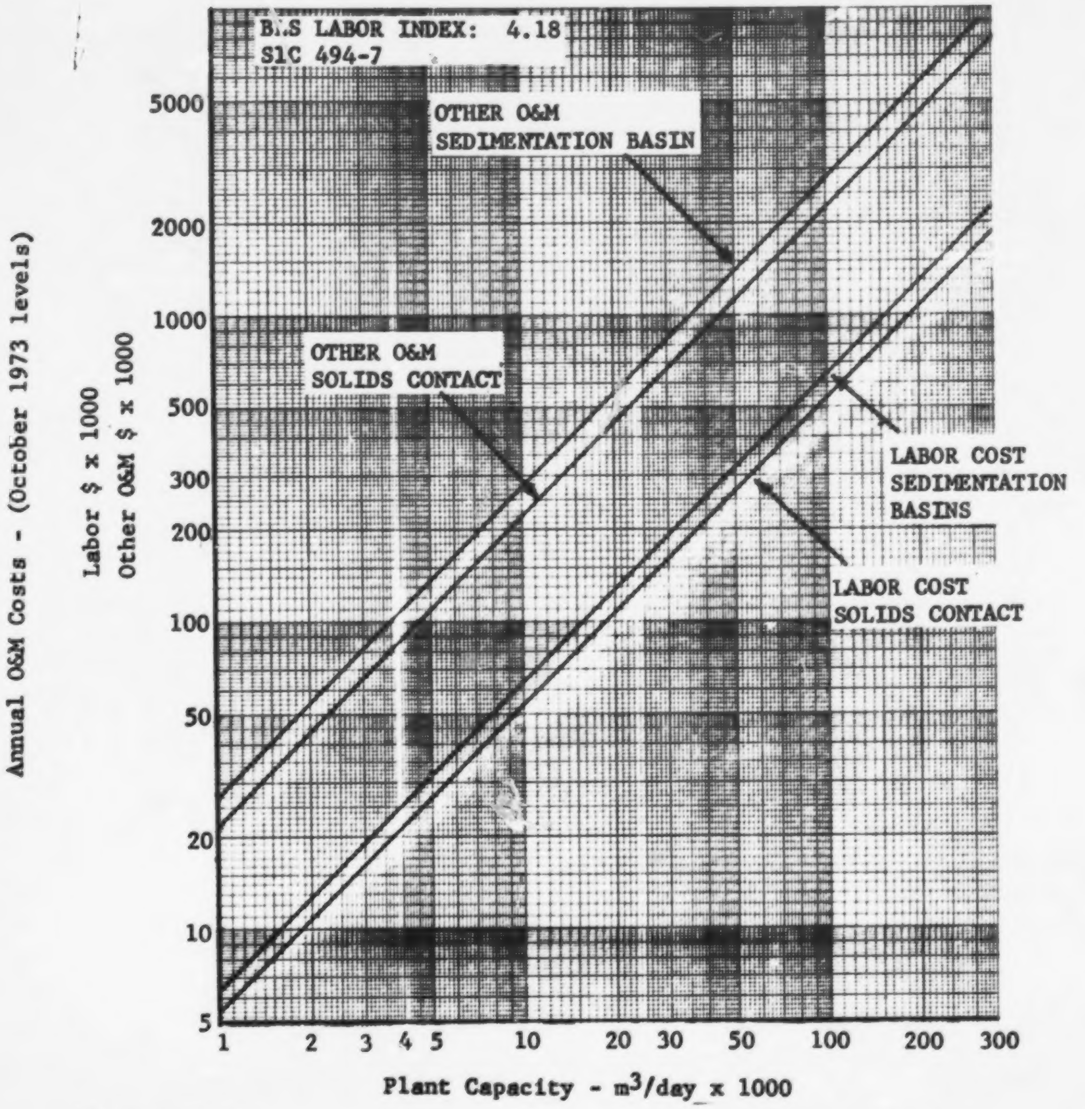


Plant Capacity - m^3/day x 1000

Includes	Excludes
Grubbing, clearing and grading	Owner's general expense
Roads	Interest during construction
Fences and gates	Land Cost
Utilities	
Service Buildings	
Design and Specifications	
Construction Supervision	

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure CS-3 - Site Development Costs Coagulation and Sedimentation



Cost includes	**Does not include**
Labor payroll	Major repair items
Payroll overheads and extras	Labor for major repairs
Regular maintenance items	
Consumable supplies	

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure CS-4 - Operating and Maintenance Costs Coagulation and Sedimentation

FILTRATION

a. Rapid Sand Filter

The rapid sand filter is the most widely used method of filtration presently used for drinking water preparation. The filter medium has traditionally been sand of approximately 0.5 mm effective size, but recently, crushed anthracite has been employed either in conjunction with sand or by itself. With either filter medium the filtration rate is approximately 4 to 10 $m^3/ m^2/hr$.

Rapid filters cannot reduce the turbidity to the level of 5 units with raw water feed whose turbidity is greater than 15 units (Figure RF-1) unless the water is coagulated or filter aids are used. In water that has been coagulated, particle sizes range from 2 mm to less than o.1 mm. In a bed of sand of 0.5 mm particle size, pore openings are between 0.1 mm and 0.2 mm. In angular media such as coarser anthracite, the pore openings are 0.3 mm to 0.6 mm. It follows then that the larger floc particles will be surface strained while the smaller particles will penetrate the bed. These internally - collected particles will tend to shear and break as the hydraulic gradient through the bed increases. Thus it is important for efficient filtration that a strong floc be promoted during the coagulation process.

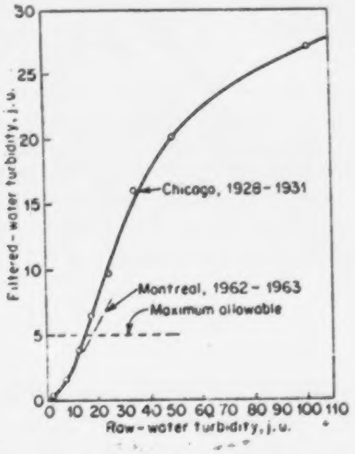


Figure RF-1 - Removal of Turbidity by Rapid-Sand Filtration Without Flocculation, 0.5 mm sand,

Currently, a number of treatment plants in the United States are routinely producing filtered water, with coagulation and sedimentation ahead of filtration, with final turbidity less than 0.1 units.

When turbidity of the raw water is low, a coagulant together with a coaulant aid and the necessary pH adjustment may be used prior to direct filtration. For example, this coagulant dose should be a maximum of 15 grams/m^3 of aluminum sulfate. Larger doses would produce rapid clogging of the filter. If zeta potential tests show that this is sufficient coagulant for the raw water, a product water will result with turbidity averaging less than 1 unit. It should be noted that tests should be made to determine the complete range of raw water turbidity likely to be encountered, otherwise peaks could occur which might precipitate total blocking of the filter and turbidity breakthrough.

b. Slow Filters

Slow filters were the original filters used in municipal treatment and have largely given way to rapid filters in the United States, although they are still used in Europe. Filtration rates are 0.125 $m^3/m^2/hr$ to 1.25 $m^3/m^2/hr$, compared to the minimum rate of 4 $m^3/m^2/hr$ for rapid filters.

The efficient operation of a slow filter depends on the establishment of a biological growth layer on the surface of the filtering media. The coagulation of the colloidal turbidity is accomplished by enzymes secreted by this growth, which is commonly known as a "biological membrane" or "schmutzdecke".

The filtration is generally accomplished at three separate rates.

Coarse filtration	0.83 to 1.25 $m^3/m^2/hr$
Prefiltration	0.42 to 0.83 $m^3/m^2/hr$
Final filters	0.125 to 0.29 $m^3/m^2/hr$

Good filtration is obtainable provided the raw water does not contain large concentrations of suspended solids, and the final filters are kept at a low rate. Additionally, the possibility of using the biological characteristics for the removal of organic contaminants such as foaming agents and pesticides could exist. However, maximum possible removal is only about 50%, and this, coupled with the relative size and limited turbidity effectiveness of the slow filter makes it a generally impractical application.

c. Diatomaceous Earth Filters

Diatomaceous earth filters are a recent development in water treatment not yet very widely used in the United States, except in specific applications such as for swimming pools.

The diatomite filter is a pressure or vacuum process which uses a porous support called a septum, precoated with diatomaceous material as the filter medium. The water to be treated also contains the diatomite as a body feed to assist in the filtration process, together with proprietary products known as filter aids. A limitation for applying this technique to water is that the turbidity must be low, otherwise excessive clogging of the septum occurs, resulting in short runs and excessive backwashing.

Limited data on diatomaceous earth filtration exists for actual field applications.

A water treatment facility constructed at Lompoc, California incorporates a precoat filter using diatomaceous earth as part of a complete municipal system. Since the Lompoc area is the site of large deposits of diatomaceous materials, certain cost advantages were obvious. Several plants are also in existence in Canada, where a number of installations have been specified for iron removal, an operation very suited to the precoat filter characteristics. Much work has been done on the filtration of secondary treated sewage. Data for some of this work is shown in Table DF-1.

Professor Baumann and his colleagues at Iowa State University have done substantial research into filtration operations and economics, including diatomaceous earth filtration. They have concluded that diatomite filters are competitive with sand filters under certain conditions of raw water quality, and that vacuum filters are preferable to pressure filters from the operational standpoint.

Technical data from the Celite Division of Johns Manville indicates that diatomite filtration plant costs are well below those of conventional plants up to about 40,000 m^3/day. For recommended filtration rates of 2.5 m^3/m^2/day to 5 m^3/m^2/day, this is a filtration area of 8,000 m^2 to 16,000 m^2.

From an AWWA committee paper on the subject, the following advantages may accrue under favorable conditions:

> "a. When filtration only is required, a substantial savings in space and first cost can be realized. As additional pretreatment or post-treatment is required, the margin becomes less.
>
> b. For a low concentration of filterable solids, treatment costs are significantly less than conventional coagulation - sand filtration.
>
> c. Generally the process is purely mechanical and not dependent on chemical reactions which require greater operator expertise.
>
> d. The amount of backwash liquid is significantly less and the solids, although generally larger in bulk, are easily dewatered and may have the economic feasibility of some recycling."

In any event, careful preliminary testing of the feed-water must be concluded in conjunction with cost comparision with conventional filtration prior to a process being selected.

Diatomite filters have also been demonstrated successfully as supplementary treatment for the following:

i. Iron removal, either by pre-oxidation, or by the introduction of magnesite, MgO, into the water with 5 to 10 minutes reaction time.

ii. Manganese removal, by pre-oxidation with potassium permanganate and a 10-15 minute reaction time.

iii. Taste and odor removal,by installing diatomite equipment ahead of activated carbon filters, the organic loading on the carbon is reduced, extending its life and making the process cost competitive with the use of powdered carbon pre-treatment.

iv. Mercury removal; by conversion of the soluble mercury salts to the insoluble form, followed by diatomite filtration, mercury levels can be reduced to .005 mg/l from a feed concentration of 5 mg/l.

Cost data for diatomite filters are in Figures DF-1 through DF-5. Typical properties of some diatomite materials are shown in Table DF-2. Cost for annual maintenance supplies can be computed as 2% of the construction cost per year.

TABLE DF-1

VACUUM DIATOMACEOUS EARTH FILTRATION OF SECONDARY SEWAGE EFFLUENT[1]

Flow Rate liter/sec m^2	Filter Aid	Body-feed Conc. (mg/l)	No. of Runs	Run-length (hrs)	Turbidities (JTU)		% Reduction
					Feed	Product	
.36	Celite 545	42	5	19.5	5.5	0.8	85.5%
.51		33	3	10.7	5.2	0.8	84.7%
.68		19	1	5.4	4.4	0.4	91%
.35	Celite 503	36	2	8.0	10.5	3.3	68.6%
.51		29	1	3.0	9.2	0.7	92.4%
.68		21	1	1.2	8.0	0.75	90.7%
.37	Hyflo Super-Cel	35	6	12.7	4.6	0.85	81.6%
.51		21	2	4.4	5.8	0.8	86.2%

Precoat - .49 Kg/m^2
Headloss at end of run - 457.2 mm Hg

PRESSURE DIATOMACEOUS EARTH FILTRATION OF SECONDARY SEWAGE EFFLUENT[1]

Flow Rate (gpm/ft^2)	Filter Aid	Body-feed Conc. (mg/l)	No. of Runs	Run-length (hrs)	Turbidities (JTU)		% Reduction
					Feed	Product	
.34	Celite 545	50	1	50.0	8.2	3.1	62.2
.51		19	2	28.4	5.7	2.5	56.2
.55		42	2	24.2	5.7	2.5	56.2
.68		20	2	7.3	6.4	2.1	67.2
.68		45	3	31	7.5	3.0	60.0
.52	Celite 503	18	1	14.5	7.0	4.0	42.9
.53	Hyglo Super-Cel	21	1	22.3	8.1	4.9	39.6
.81		29	1	9.7	6.5	3.8	41.6

Precoat - .49 Kg/m^2
Head loss at end of run - 1808.48 mm Hg.

---

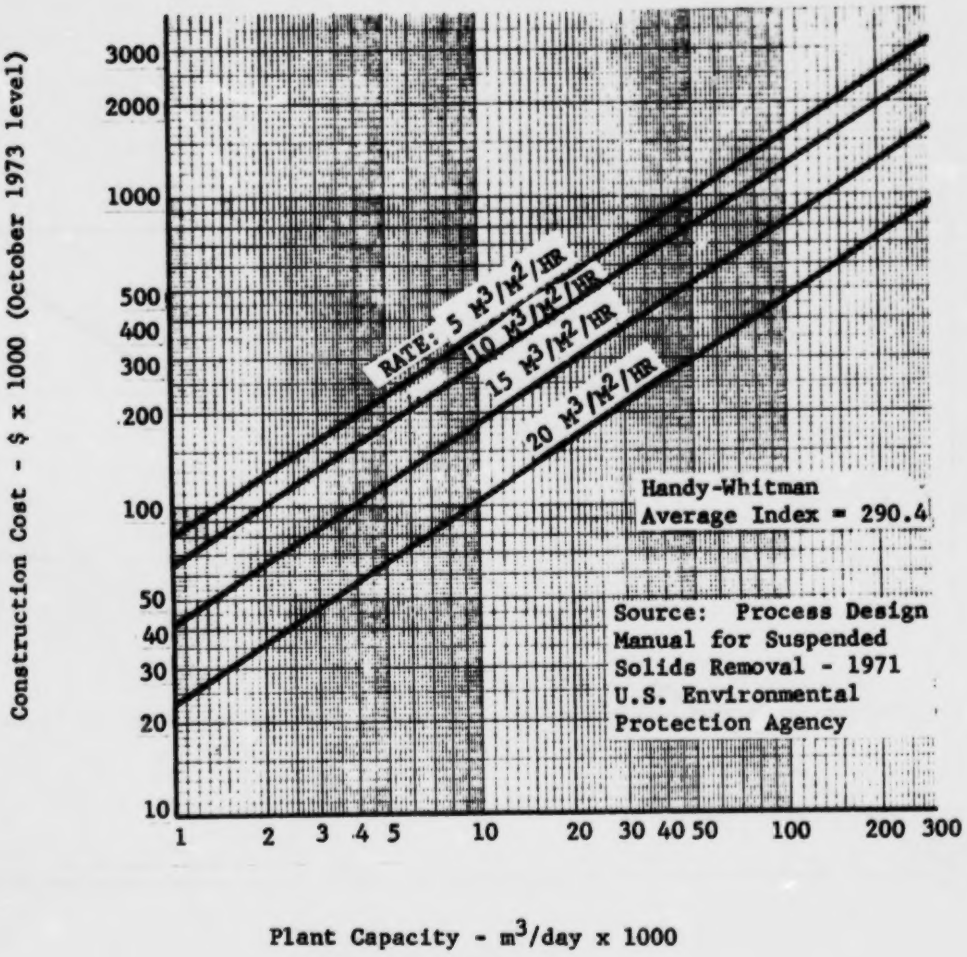
[1] Process Design Manual for Suspended Solids Removal for E.P.A., Technology Transfer, p. 8-20, October, 1971.

TABLE DF-2
TYPICAL PROPERTIES DIATOMITE FILTERS[1]

Type	Grade	Color	kg/m^3 Density		Screen Analysis % Undissolved Retained by 150 Mesh	Relative* Flow Rate	pH
			Dry	Wet			
Natural	Filter-Cel	Gray	112.	255	1.0	100	7
Calcined	505	Pink	128.	336	--	135	7
	Standard Super-Cel	Pink	128.	276	3.0	200	7
	512	Pink	128.	287	4.0	300	7
Flux Calcined	Hyflo Super-Cel	White	144.	276	5.0	500	10
	501	White	152.	271	8.0	750	10
	503	White	152.	276	9.0	900	10
	535	White	192.	282	9.0	1350	10
	545	White	192.	288	12.0	2160	10
	550	White	290.	366	20.0	2380	8
	560	White	312.	320	50.0	7500	10

* as particles of suspended matter which must be removed decrease in size, flow rate decreases. Grade selected is dependent on size of particles to be removed. Flow rate varies with time, being 0 at start up and leveling off at operating flow rate 1 to 20 hours after start up depending on grade selected.

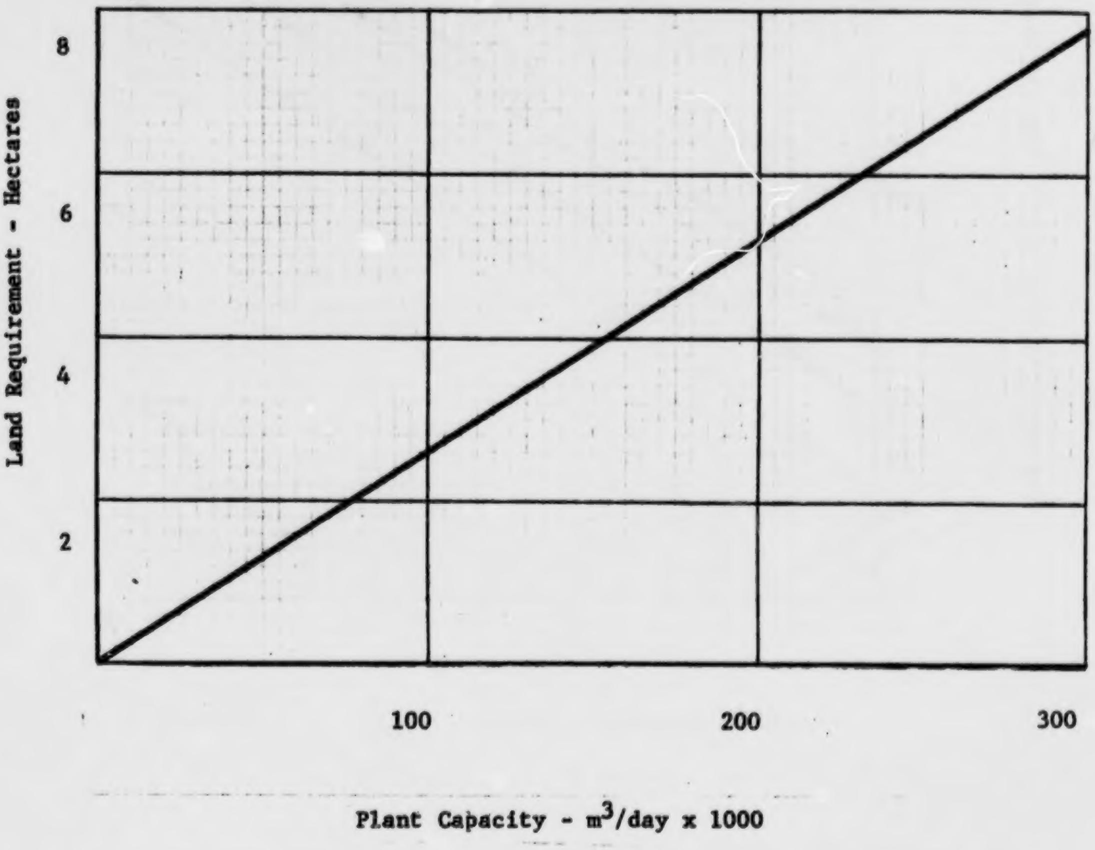
[1] Johns Manville Celite Division, Greenwood Plaza, Denver, Colorado, May, 1972.



Cost includes	Cost does not include
Concrete structures	Land
Foundations	Site development
Piping and underdrains	Owner's general expense
Controls	Interest during construction
Designs and Specifications	
Construction Overhead	

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

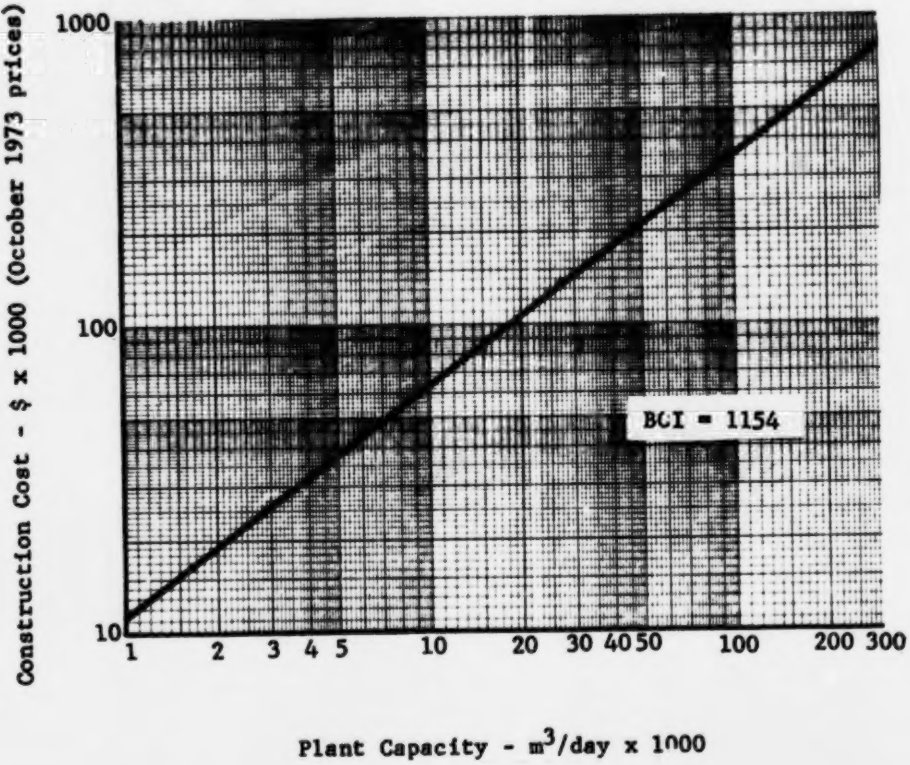
Figure RF-2 - Construction Cost for Rapid Filter



Minimum land requirements - .1 hectare

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure RF-3 - Land Requirement for Rapid Sand Filters



Includes

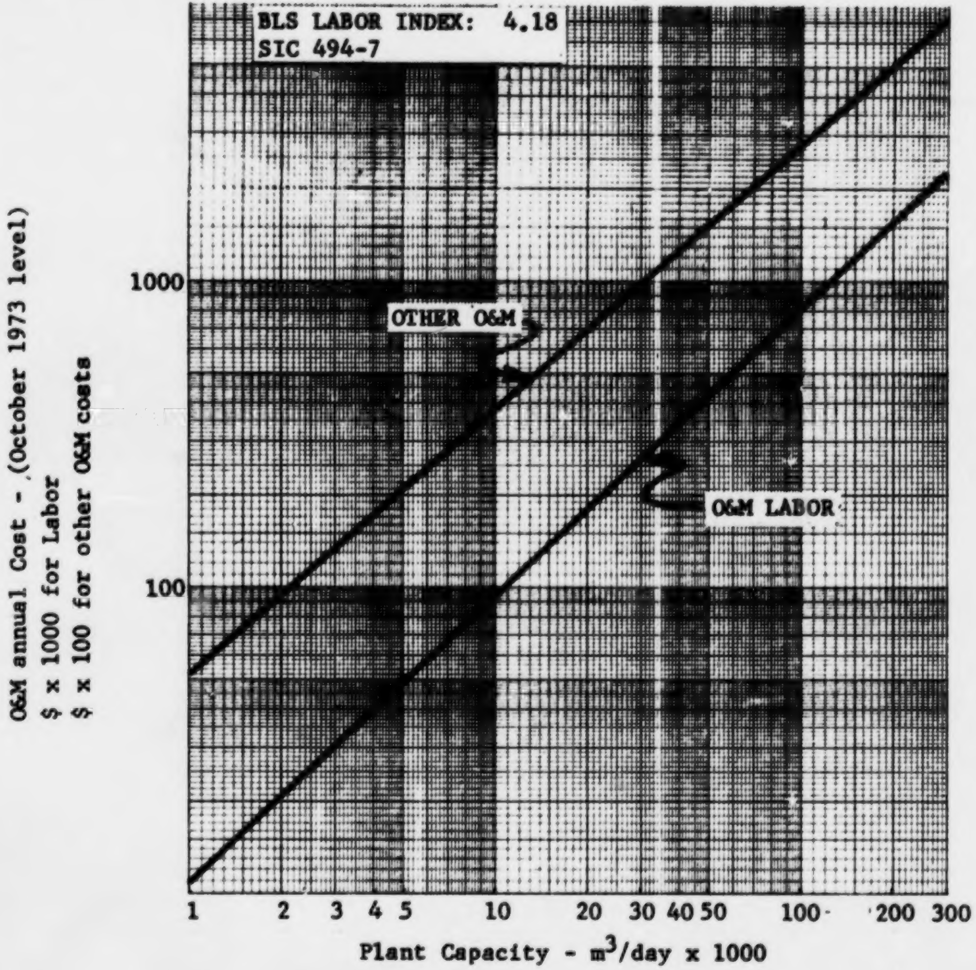
Grubbing, clearing and grading
Roads
Fences and gates
Utilities
Service Buildings
Design and Specifications
Construction Supervision

Excludes

Owner's general expense
Interest during construction
Land Cost

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure RF-4 - Site Development Costs for Rapid Filters



Cost include

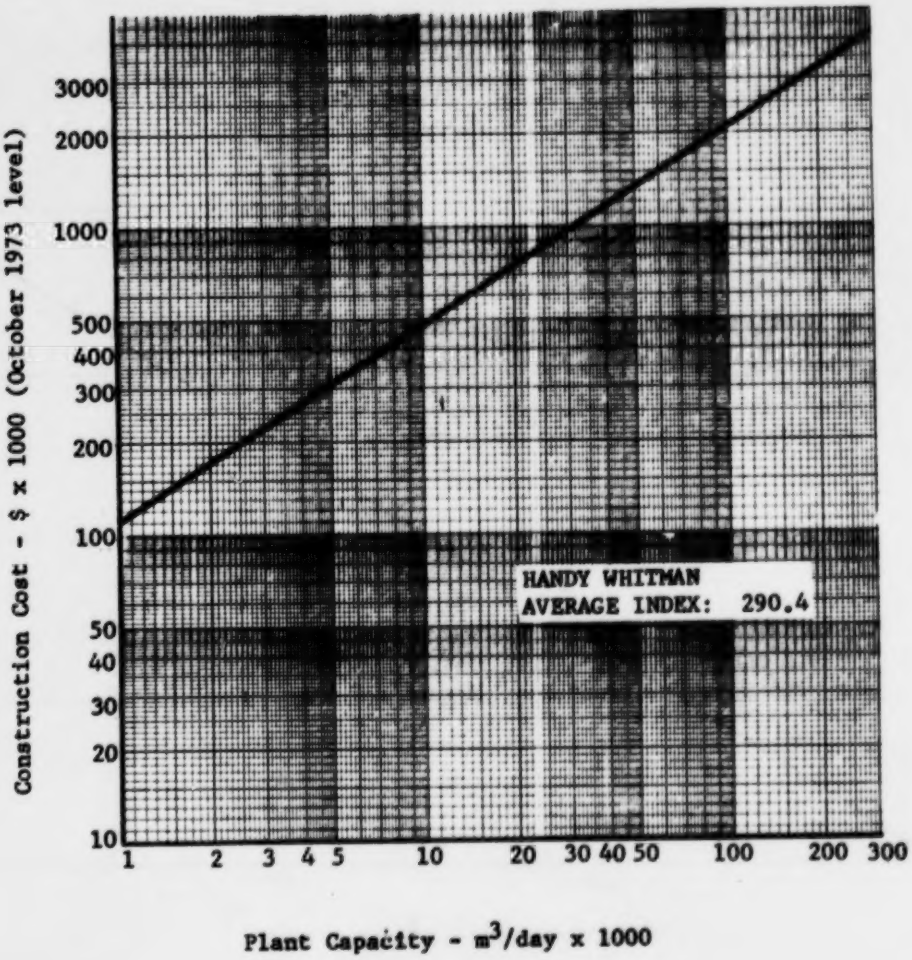
Labor payroll
Payroll overheads and extras
Regular maintenance items
Consumable supplies

Does not include

Major repair items
Labor for major repair

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

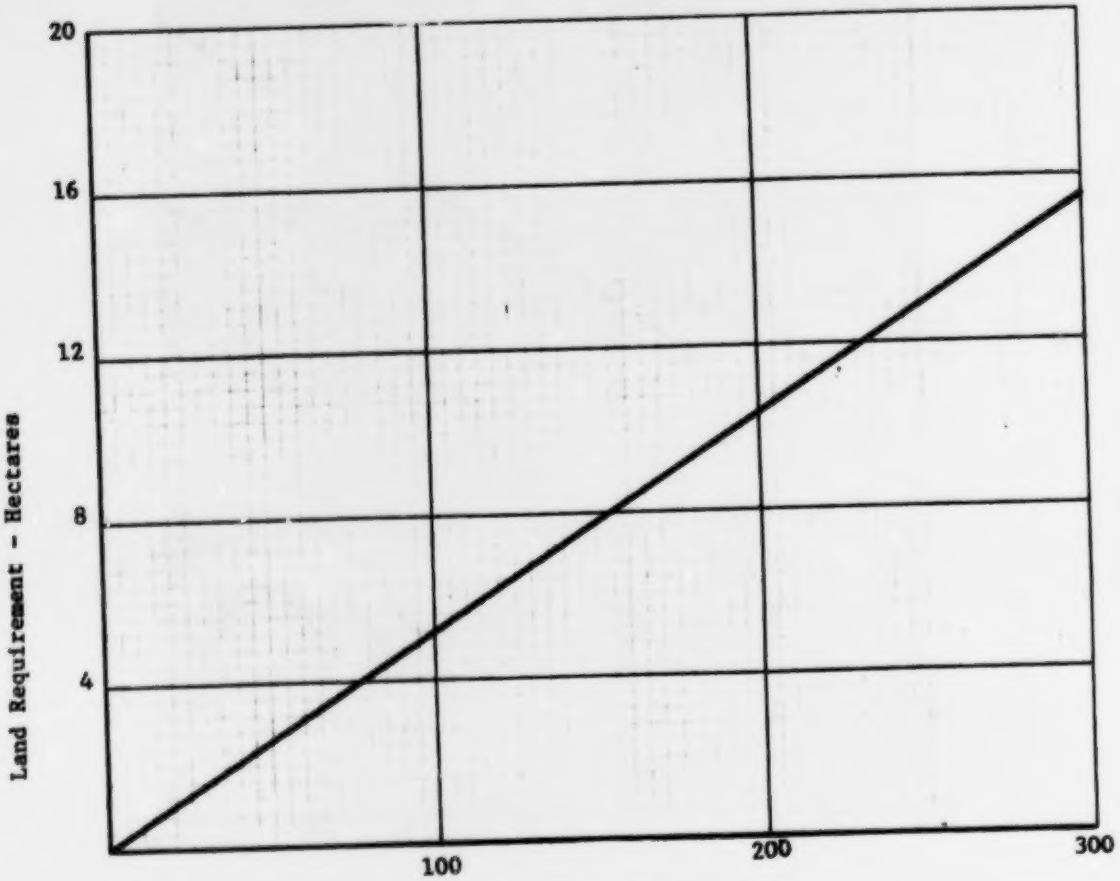
Figure RF-5 - Operating and Maintenance Costs-Rapid Filtration



Cost includes	Cost does not include
Concrete structures	Land
Foundations	Site development
Piping and underdrains	Owner's general expense
Controls	Interest during construction
Media loading	
Designs and Specifications	
Construction Overhead	

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

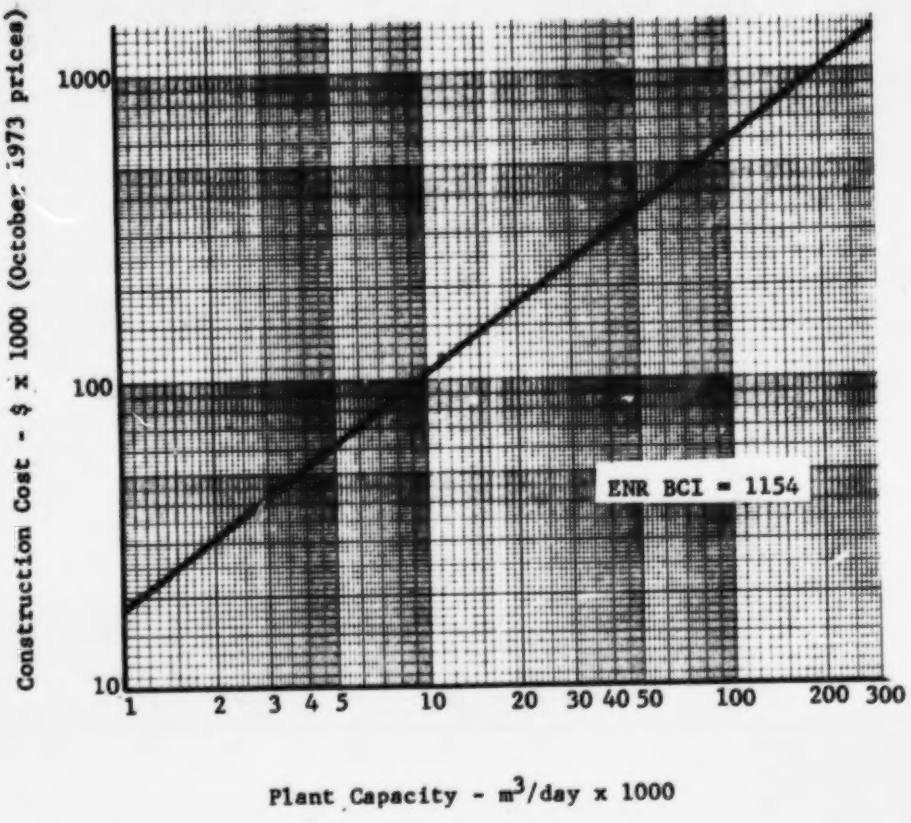
Figure SF-1 - Construction Cost for Slow Filters.



Minimum Land Requirement = .1 hectare

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure SF-2 - Land Requirement for Slow Sand Filters



Includes

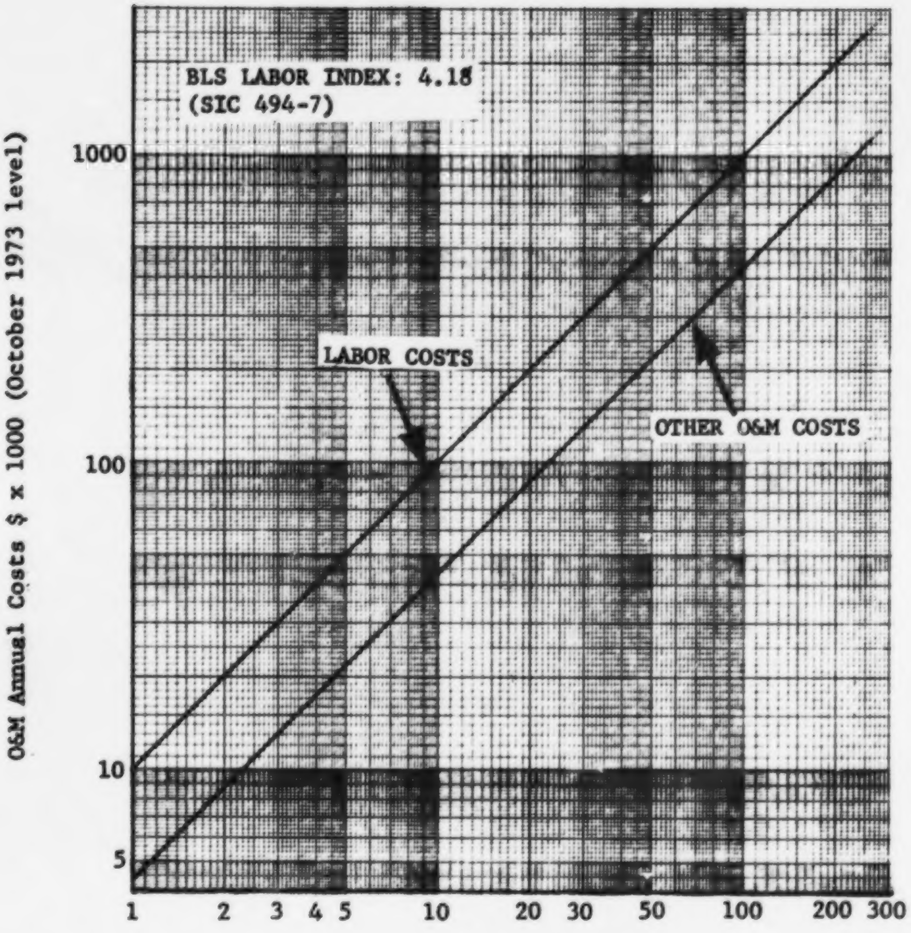
Grubbing, clearing and grading
Roads
Fences and gates
Utilities
Service Buildings
Design and Specifications
Construction Supervision

Excludes

Owner's general expense
Interest during construction
Land cost

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

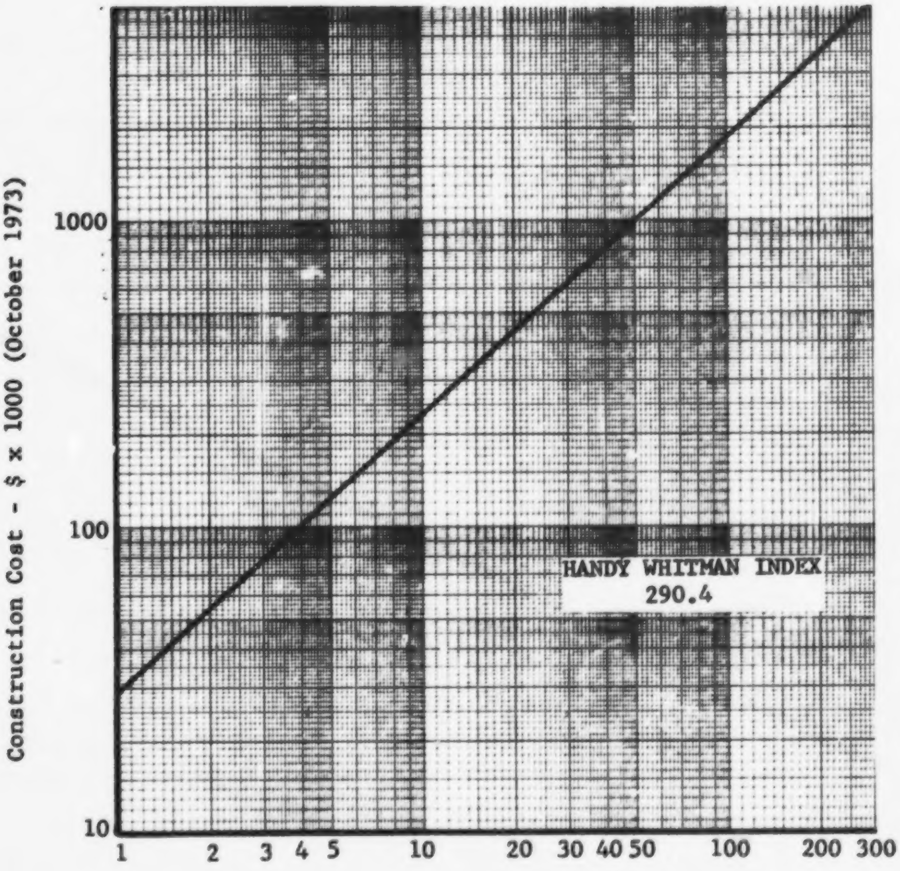
Figure SF-3 - Site Development Costs for Slow Filters



Costs include	Does not include
Labor payroll	Major repair items
Payroll overheads and extras	Labor for major repair
Regular maintenance	
Consumable supplies	

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure SF-4 - Operating and Maintenance Costs Slow Filters

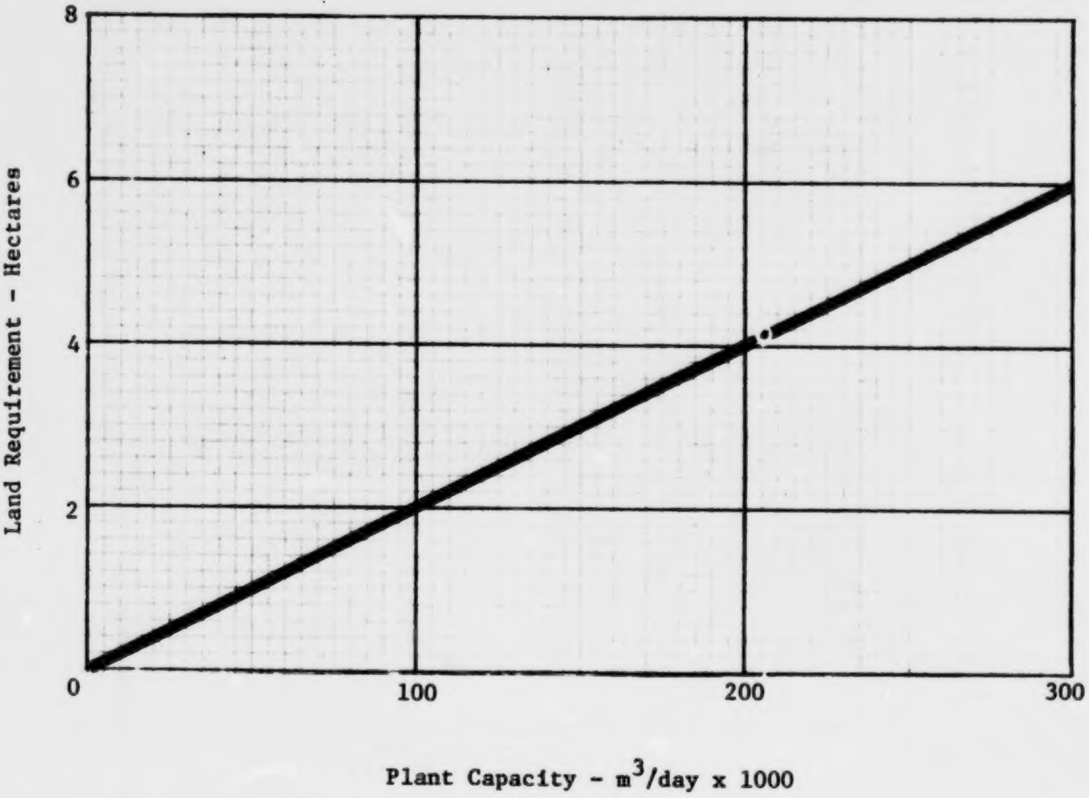


Plant Capacity - m^3/day x 1000

Costs Include	Costs Do Not Include
Filtration Equipment	Owner's general expense
Pumps, piping and valves	Interest during construction
Instrumentation and controls	Land cost
Civil works	
Site Development	
Service buildings	
Engineering fees	
Construction O/H	

Source - Environmental Planning and Engineering Division, of David Volkert & Associates

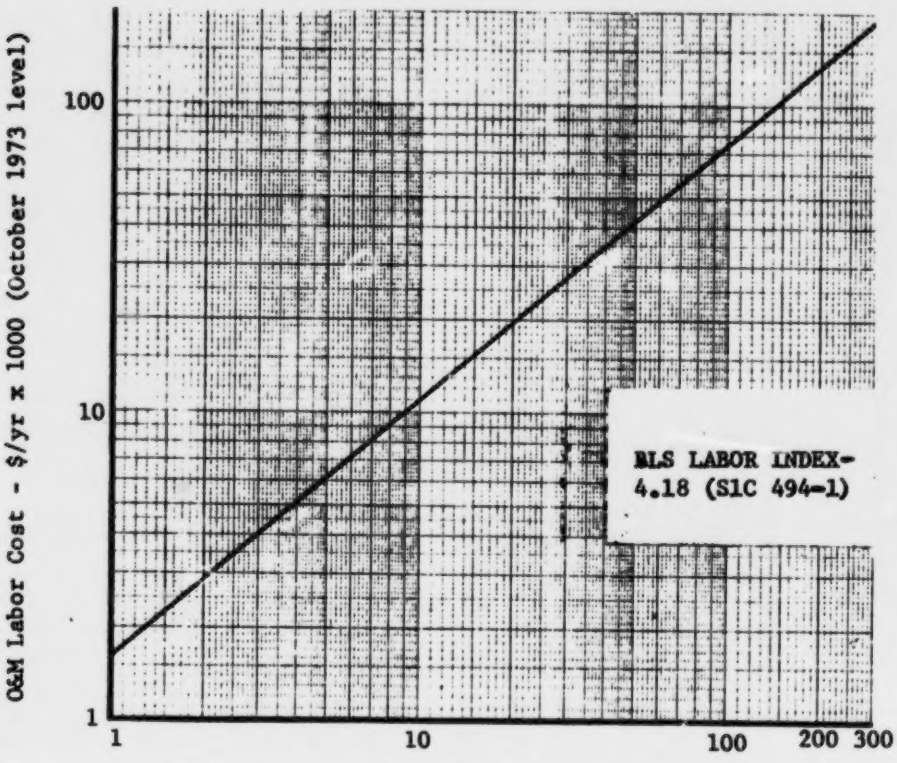
Figure DF-1 - Construction Cost Diatomaceous Earth Filters



Minimum Land Requirement is .1 hectare.

Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure DF-2 - Land Requirement for Diatomite Filtration



Plant Capacity - m^3/day x 1000

Cost Includes

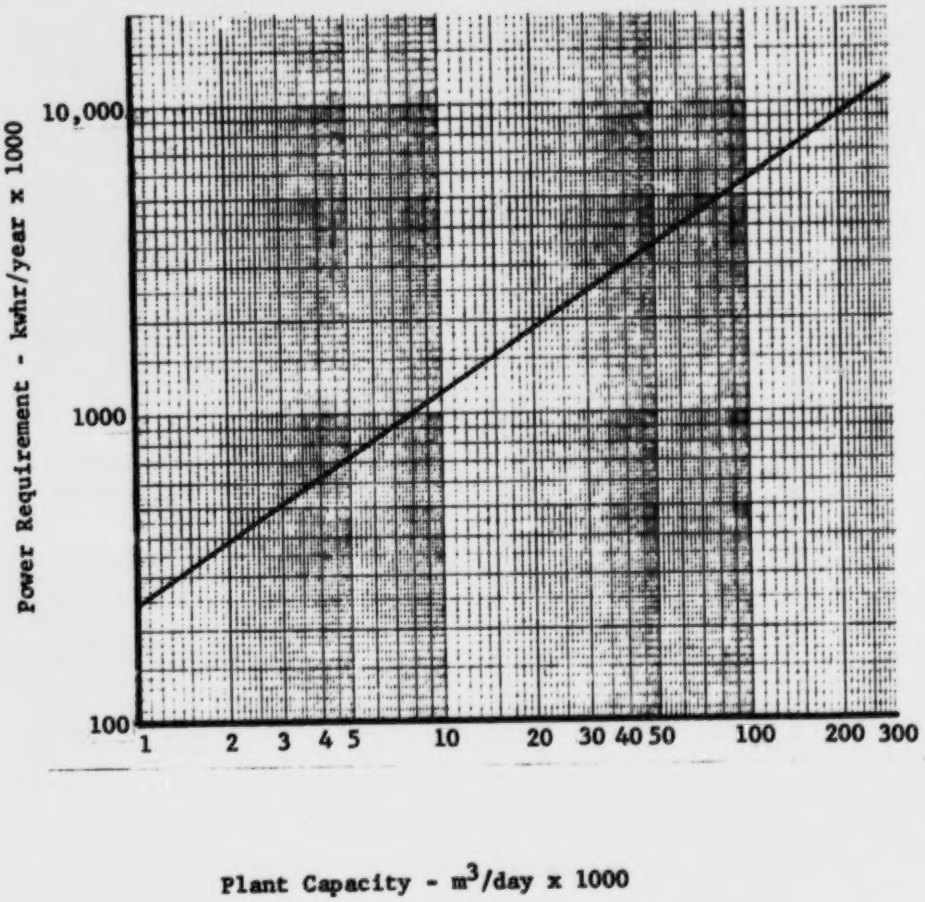
Labor Salaries
Overhead and Payroll Extras
Administrative Expense

Cost Does Not Include

Labor Cost for Major
Repairs or Replacement

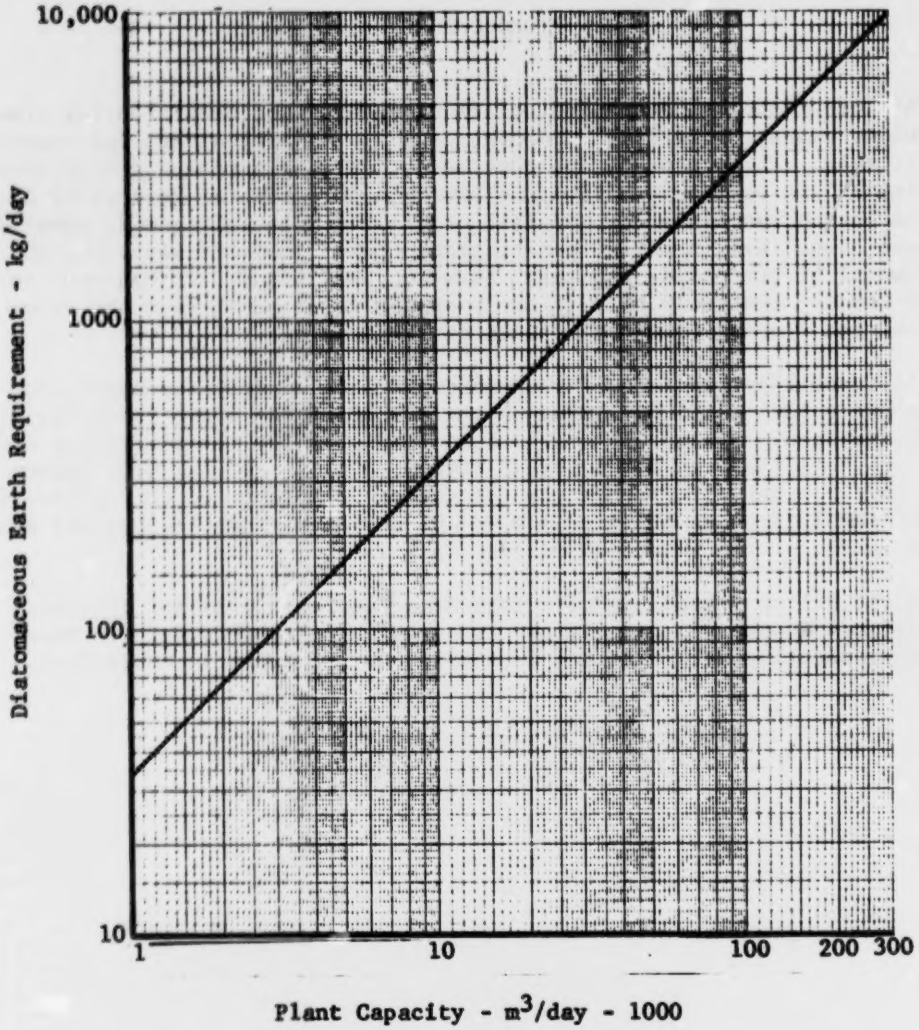
Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure DF-3 - O&M Labor Cost, Diatomite Filtration



Source - Environmental Planning & Engineering Division,
of David Volkert & Associates

Figure DF-4 - Power Requirement, Diatomite Filtration



Note: Costs for diatomaceous earth are 10¢/kg for Midwest, 12¢/kg for FOB Eastern U.S. and 9¢/kg FOB West Coast.

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure DF-5 - Diatomaceous Earth Requirement

MICROSCREENING

This technique for suspended solids separation has been used for some twenty years, primarily in Europe, as a tertiary treatment for sewage effluent. The equipment consists essentially of a rotating drum frame with a fine mesh screen covering having a pore size of down to 23 microns. The screen can either be metallic or plastic material, and is woven in such a way that it allows penetration of the backwash water for the removal of the solids mat which forms on the inside. It has been noted in studies that only half of the backwash water penetrates the screen, the rest flowing down the outside of the drum.

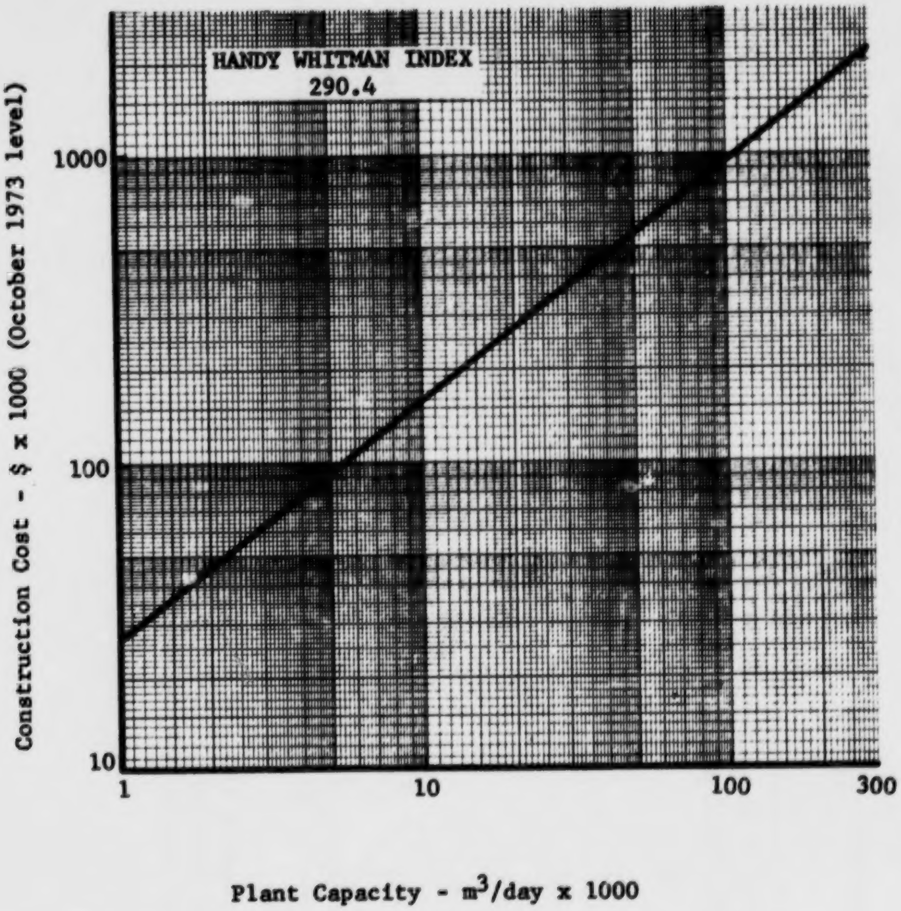
The removal performance of the microscreen is largely dependant upon the mat of solids which builds up on the inside of the drum, since the size of the opening, although small, cannot account for the filtration efficiency alone. It has been demonstrated (Lynam, et. al, Journal WPCF Volume 41, p 247, February 1969) that the filtration efficiency of the microscreen is heavily dependent upon the speed of rotation, and the physical characteristics of the suspended solids.

In the United States, microscreens have been used only for treatment of tertiary sewage and not for the preparation of potable water. Some representative data obtained from this use are shown in Table MS-1.

TABLE MS-1-TERTIARY TREATMENT BY MICROSCREENERS

Location	Screen Size (Microns)	Plant Size (m^3/day)	S.S. (Rem.%)	BOD (Rem.%)	Backwash (%)	Manu-facturer
Luton, England	35	13,626	55	30	3.0	Crane
Bracknell, England	35	27,252	66	32	N.A.	Crane
Harpendon, England	35	1,136	80	N.A.	N.A.	Crane
Brampton, Ontario	23	379	57	54	N.A.	Crane
Chicago, Illinois	23	7,570	71	74	3.0	Crane
Lebanon, Ohio	23	Pilot	89	81	5.3	Crane
	35	Pilot	73	61	5.0	Crane

Source - Process Design Manual for Suspended Solids Removal for E.P.A., Technology Transfer, p. 8-12, October 1971, supplemented by information gained from equipment vendors.



Cost Includes

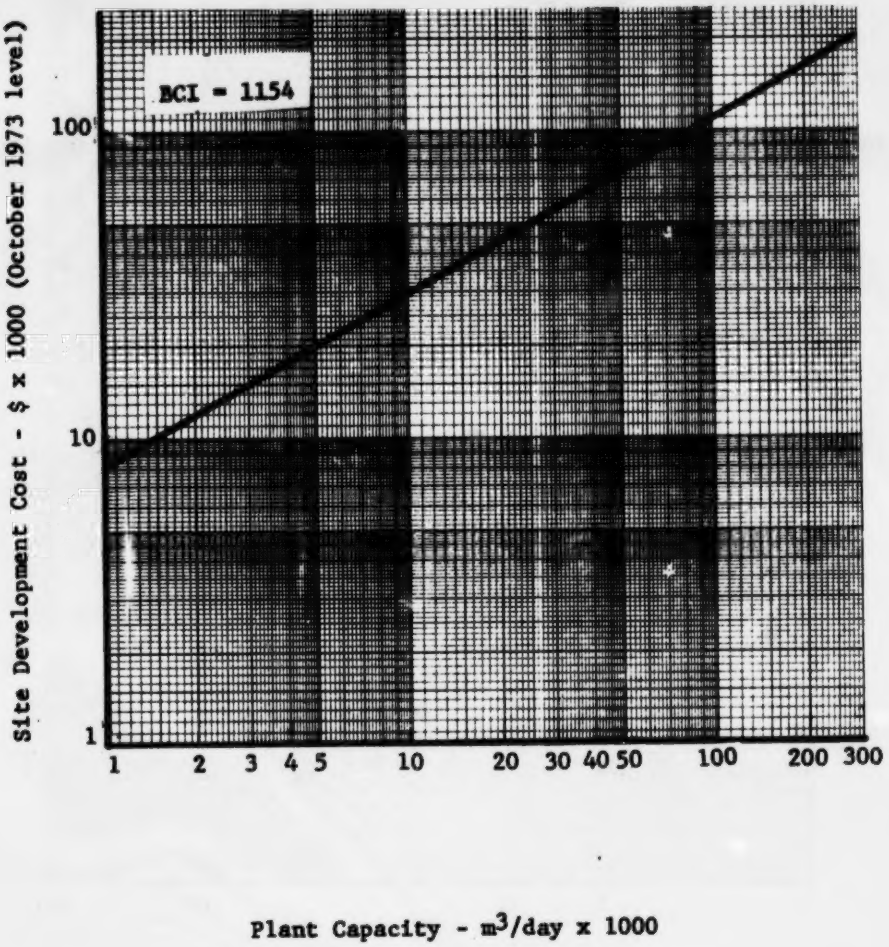
Microscreening Equipment
Pumps, piping and controls
Foundation and Civil Works
Design and Specification
Construction Supervision

Cost Does Not Include

Interest during construction
Land cost
Owner's General Expense

Source - Process Design Manual for Suspended Solids Removal for E.P.A., Technology Transfer, p. 11-9, October 1971. Calculations by Environmental Planning & Engineering Division, of David Volkert & Associates

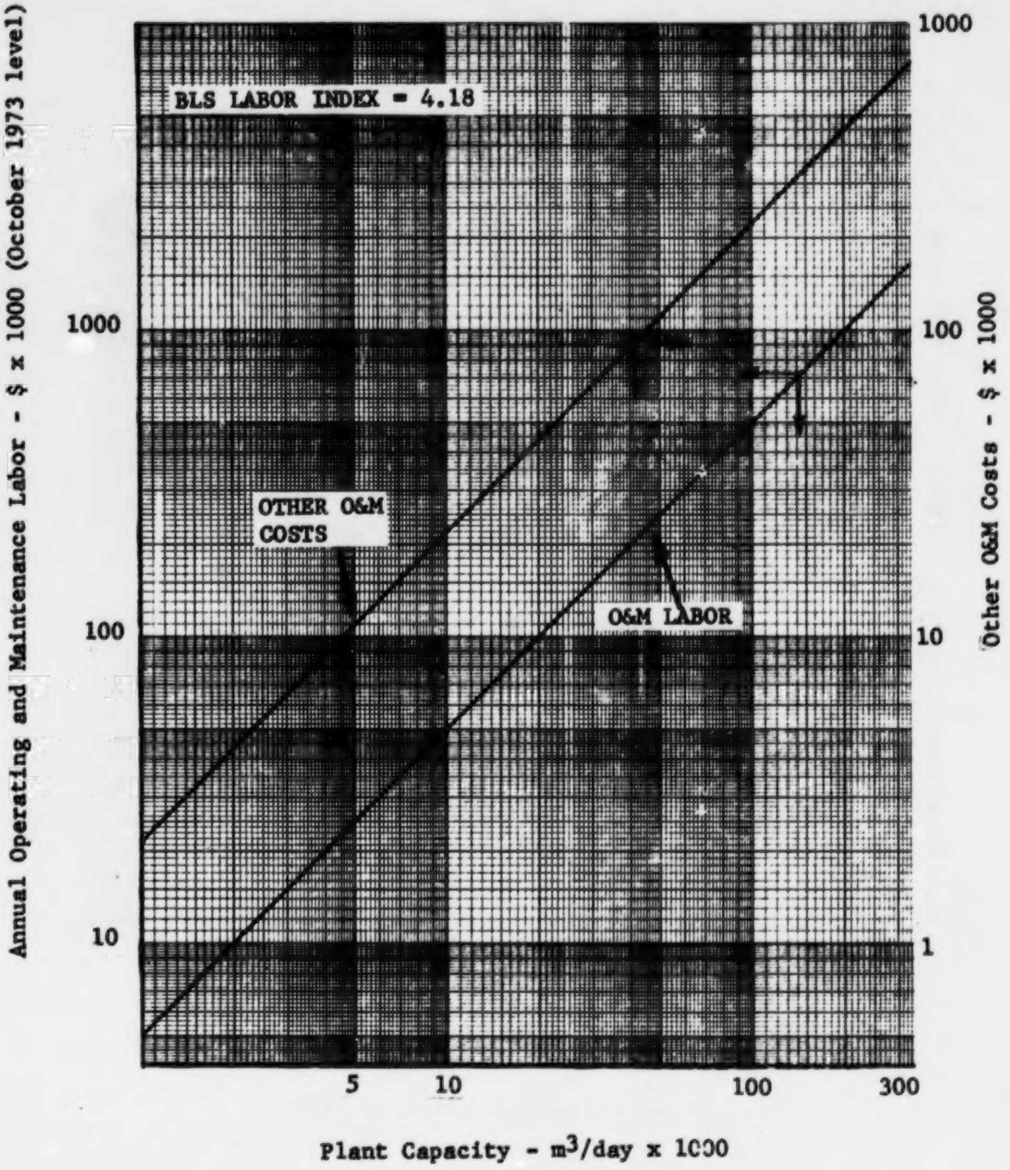
Figure MS-1 - Microscreening Construction Cost



Cost Includes	Cost Does Not Include
Buildings and Services	Land Cost
Site preparation costs	Owner's General Expense
Fencing and landscaping	Interest during construction
Site utilities	
Design and Specifications	

Source - Environmental Planning & Engineering Division, of David Volkert & Associates

Figure MS-2 - Site Development Cost for Microscreening



Note: Costs include O&M labor, overhead expense and payroll extras, and assume that labor is 70% of total O&M cost.

Source - Process Design for Suspended Solids Removal for E.P.A., Technology Transfer, October 1971. Calculations by Environmental Planning & Engineering Division, of David Volkert & Associates

Figure MS-3 - Annual Microscreening O&M Costs

REVERSE OSMOSIS

The reverse osmosis process uses hydraulic pressure to counteract the osmotic pressure created by dissolved minerals in the water, thus reversing the normal osmotic migration through a membrane. The pumping pressure required to provide the driving force is directly proportional to the concentration of dissolved solids in the feed, and can be computed approximately by the equation:

$$P_T = \frac{J + KP_{OS}}{K}$$

where, P_T = system pressure in atmospheres

J = membrane flux, liters/m^2/day

K = constant 0.4 liters/m^2/day per atmosphere

P_{OS} = solution osmotic pressure in atmospheres

Two other relationships useful in the design of reverse osmosis systems are:

$$J = A\ (\Delta P - P_{NO})$$

$$W_S = B\ (C_B - C_P)$$

where, J = Membrane flux

W_S = Salt permeation rate

A = Membrane constant

B = Salt permeation constant

ΔP = Effective equipment pressure

P_{NO} = Net osmotic pressure

C_B, C_P = Concentration of brine and product streams.

Generally the critical design parameters for the lowest product water cost with the desired quality are:

1. Selection of the correct membrane

ii. Selection of the optimum recovery ratio

iii. Selection of the optimum system pressure

Most membrane systems in use today use cellulose acetate as the membrane material. The hollow-fiber concept manufactured by Dupont uses a polyamide for the fiber spinning. Other membrane materials and variations of treatment for cellulose acetate have been used with varying degrees of success.

For cellulose acetate, current performance parameters are:

i. Flux (at 2000 to 3000 cm of Hg) = 34 to 56 liters/m^2/day.

ii. Salt rejection - monovalent ions - 30% to 99%
divalent ions - 80% to 99%

In addition, soluble organic compounds with a molecular weight in excess of 200 can sometimes be removed in reverse osmosis systems. (Source: manufacturer's data)

There are three types of membrane configurations currently on the market. These are tubular, spiral-wound, and hollow-fiber types.

As the name implies, the tubular type incorporates a porous wall tube with the membrane cast on the inner surface, or inserted. The concentrate or brine flow is axial with the tube, while the product flow is radial through the porous support and is collected in a shell. Several tubes are connected in series in a bundle with a single feed point, and single brine and product outlets.

The spiral-wound concept employs a sheet of membrane backing sandwiched between two sheets of membrane material. The membranes are glued together on three sides, the fourth side being glued to a perforated collector pipe. The sandwich is then wrapped around the pipe, and the whole assembly is inserted in a plastic pressure shell, equipped with appropriate connections.

The third and most unusual concept is the hollow-fiber system. In this design, millions of hollow fibers made of the membrane material are potted into a special epoxy resin tubesheet, and then inserted in a shell. The fibers themselves are 25 to 250 microns in diameter, with a wall thickness of 5 to 50 microns, thus providing a large surface area per unit volume.

Comparable packing densities for the three concepts are:

i.	Tubular	150 to 300 m^2/m^3
ii.	Spiral Wound	300 to 1000 m^2/m^3
iii.	Hollow Fiber	Approx. 30,000 m^2/m^3

The tubular concept has one major advantage over the two competitive concepts in that it has a rather large flow channel (approx. 1.5 cm^2 in diameter) and thus is less susceptible to clogging, and is easier to chemically clean. Both the hollow-fiber and spiral wound systems require extensive pre-treatment of the feed-water, including turbidity removal to less than 1 JTU.

During operation, membrane flux tends to decline with time. This relationship tends to be logarithmic in nature, and periodic cleaning will partially restore the flux. However, some decline in flux is experienced because of compaction of the membrane material when the pressure is applied. Plant designers should include a design factor to allow for flux decline.

REVERSE OSMOSIS PLANT COST CALCULATIONS

The annual cost of water produced by a reverse osmosis plant is separated into the following components:

i. Fixed annual charges - based on amortization of land and capital improvements

ii. Operating and maintenance labor cost

iii. Operating and maintenance supplies

iv. Power cost

v. Chemicals

vi. Membrane replacement

vii. Pretreatment - if required

The land requirement for a plant of particular capacity is shown in Figure RO-1. General site development costs are shown in Figure RO-2. Constructed cost for the reverse osmosis system are shown in Figure RO-3. Other cost data is obtained as follows:

i. O&M labor cost - Figure RO-4

ii. O&M supplies - computed as 1% of cost from Figure RO-3

iii. Power cost - computed as 2640 kwh/1000 m^3 of product

iv. Chemical cost - computed as \$13.00/1000 m^3 of product (BLS index for chemicals = 104.3)

v. Pre-treatment cost - computed from cost curves relating to treatment desired.

vi. Membrane replacement - computed as \$26.40/1000 m^3 at feedwater temperature of 25°C.

For feedwater at temperatures other than 25°C, a correction factor must be applied to both the plant construction cost and membrane replacement cost.

For example, assume the temperature to be 30°C, and the required plant size is 10,000 m^3/day. The cost of the plant would be found by entering the curve of Figure RO-3 with a plant capacity computed from:

In this case:

$$10000 \text{ m}^3/\text{day} \times \frac{100 + [5/9(25-30)\times 1.7]}{100}$$

$$= 10000 \times \frac{100-4.7}{100}$$

$$= 10000 \times .953 = 9{,}500 \text{ m}^3/\text{day}$$

$$\begin{array}{c}\text{Cost Calculation}\\ \text{Capacity}\end{array} = \begin{array}{l}\text{Planned}\\ \text{Capacity}\end{array} \times \begin{array}{l}\text{Correction}\\ \text{Factor}\end{array}$$

$$= \text{P.C.} \times \frac{100 + [5/9(25-T)\times 1.7]}{100}$$

where T = temperature of Feed-water in °C.

The membrane replacement cost must also be adjusted by multiplying the base cost (at 25°C) by the ratio of the two capacities

$$\text{at } T_1 = 30^\circ\text{C membrane cost is } \frac{26 \times 9{,}500}{10{,}000} = 24.7 \text{ dollars}/1000 \text{ m}^3$$

The volumes of feed-water required, and wastewater produced can be computed by the following equations:

a. Brine to product ration (BPR)* $= \dfrac{1 - (TDS_p/TDS_i)}{(900/Ca_i) - 1}$

where TDS_p = TDS concentration in product - mg/l

TDS_i = TDS concentration in feed-water

Ca_i = Calcium concentration in feed - mg/l

900 = maximum permissible calcium concentration in brine mg/l

0.11 = limiting factor for system operation

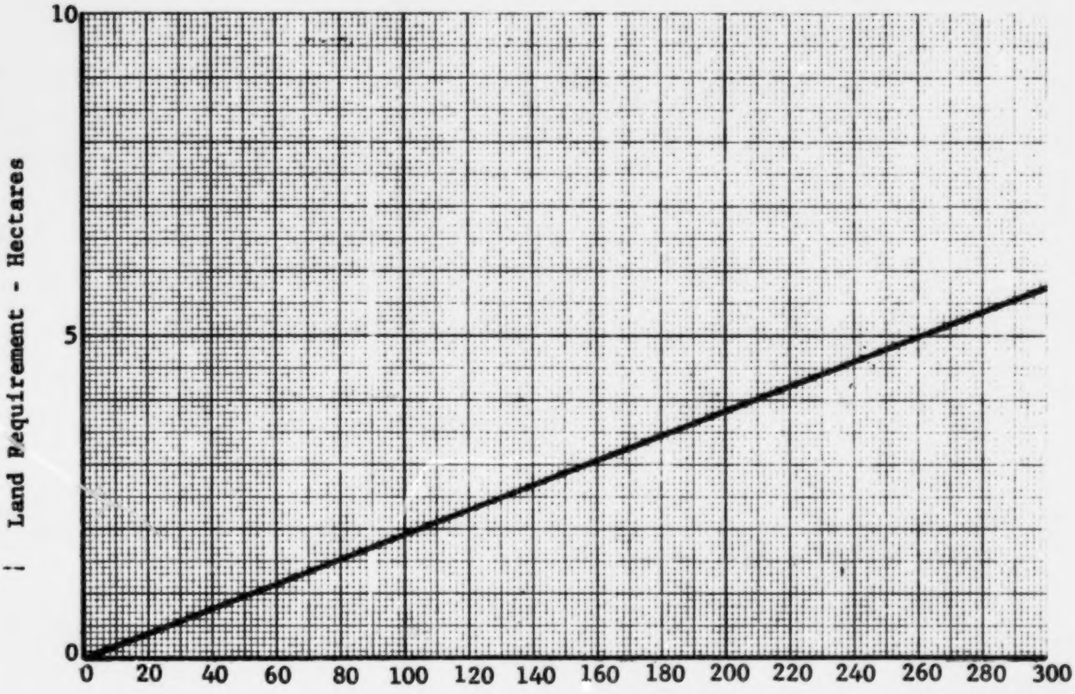
b. $V_b = B_p \times BPR$ where V_b = waste brine volume

V_p = product volume

c. $V_i = V_b + V_p$ where V_i = feed volume

---

* BPR must be greater than or equal to 0.11

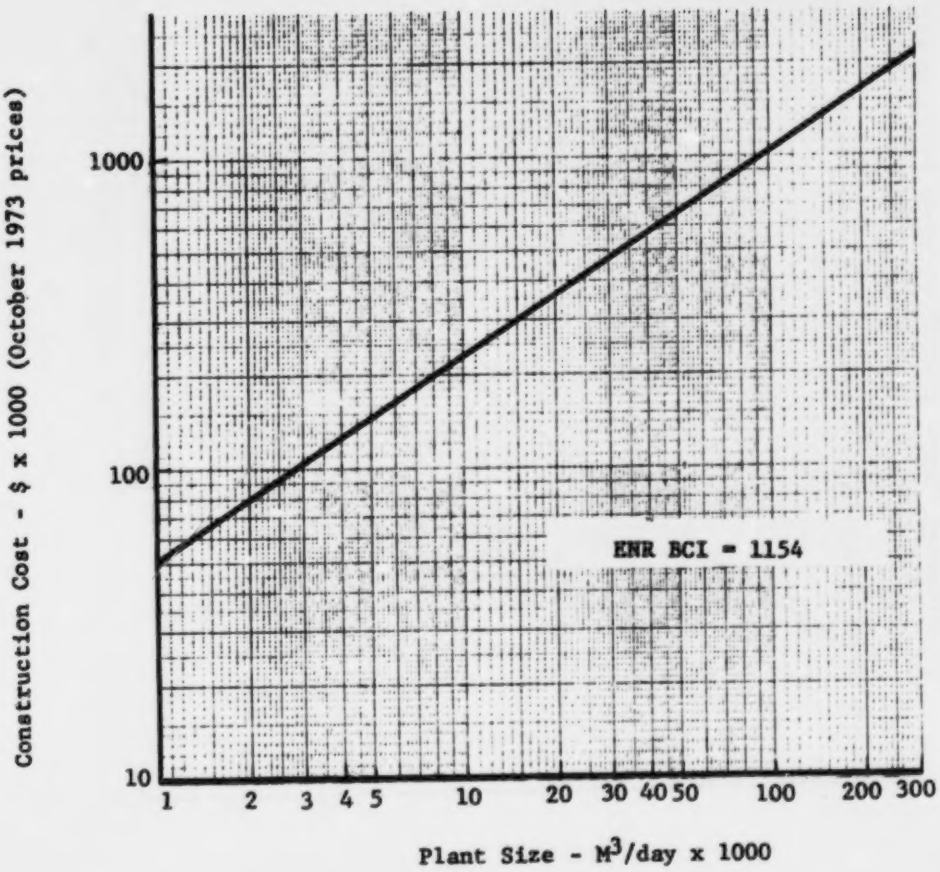


Plant Size - Cubic Meters/Day x 1000

Minimum land requirement = .1 hectare

Source - Desalting Handbook for Planners, Office of Saline Water
& the Bureau of Reclamation, Department of the Interior,
May, 1972, p. 7-53.

Figure RO-1 - Land Requirements for R.O. Installations



Includes

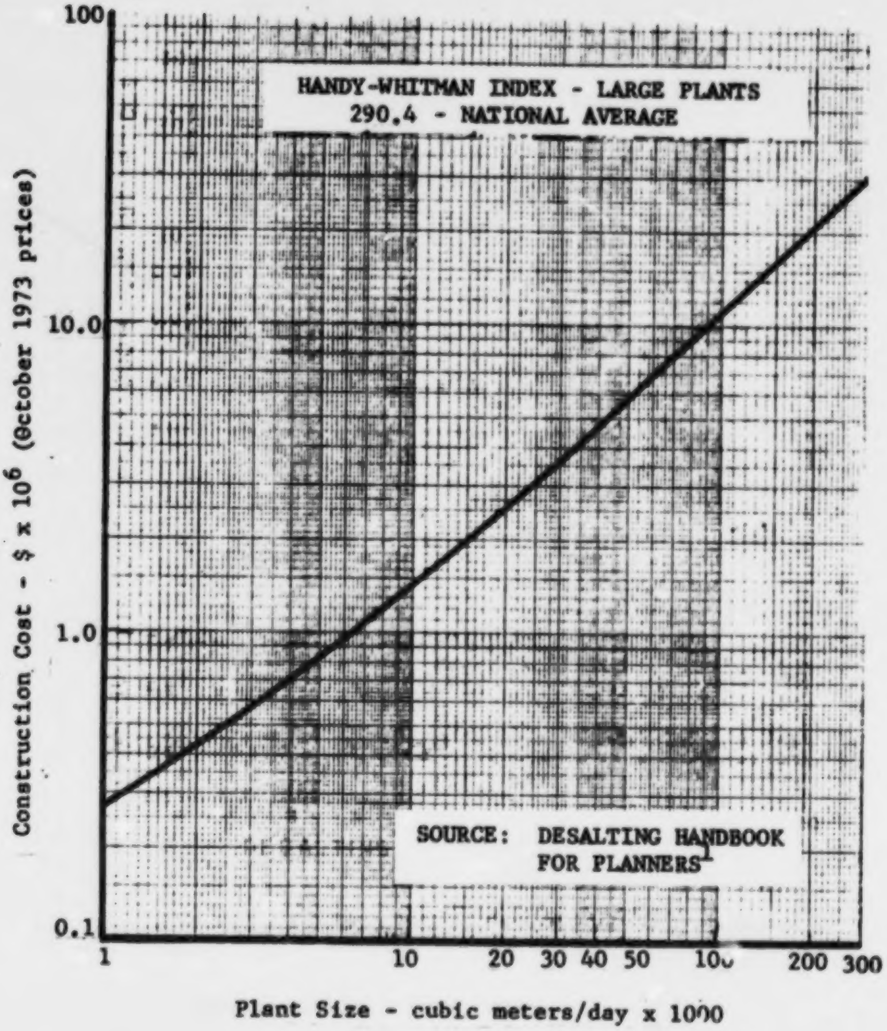
Grubbing, clearing and grading
Roads
Fences and gates
Utilities
Service Buildings
Design and Specifications
Construction Supervision

Excludes

Owner/s general expense
Interest during construction
Land cost

Source: Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972. p. 7-57.

Figure RO-2 - Site Development Costs for R.O. Plants



Construction costs include:

Membrane modules
Pressure vessels
Pumps and drives
Electrical controls
Foundations
Designs and specifications
Construction engineering
Construction supervision

Construction costs do not include:

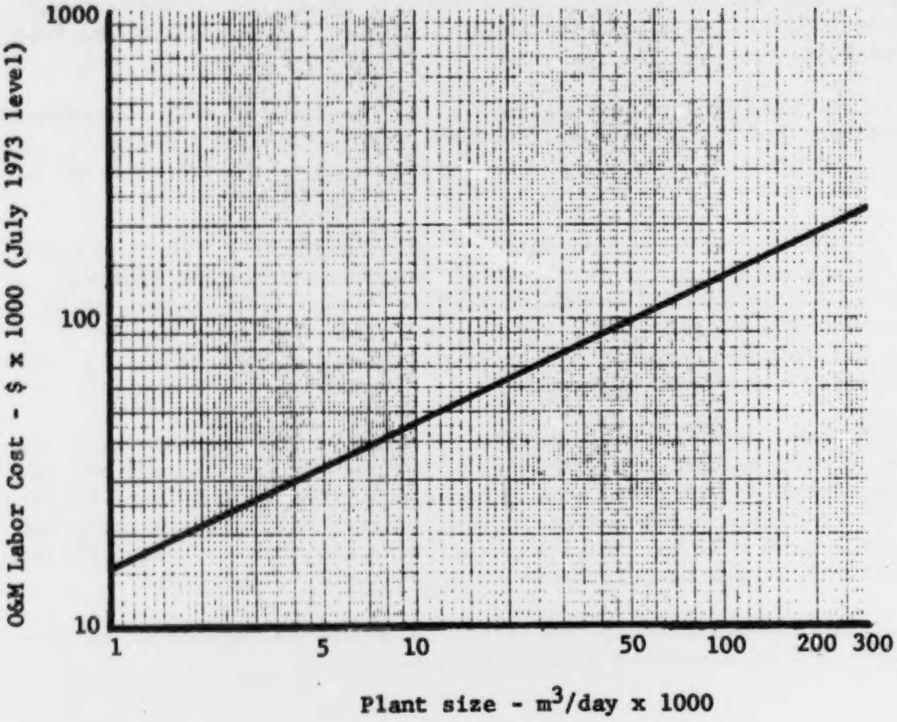
Interest during construction
Owner's general expense
Land costs
Feed water facilities
Discharge facilities
General site improvements
Product water delivery and storage
Special pretreatment facilities

Note: Plant capacity is based on feed water temperature of 25°C. Other feed water temperatures require the use of a correction factor. Refer to text. R.O. Plants generally ineffective if TDS <4000 ppm. Costs do not apply when feed-water TDS exceeds 4,000 ppm.

[1] Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-47.

Figure RO-3 - R.O. Plant Construction Costs

BLS Labor Cost Index
(SIC 494-7) = 4.18 July 1973



Includes	**Excludes**
O&M salaries and wages	Major repair labor costs
Payroll extras	Component replacement labor costs
General and administrative expenses	

Source: Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972. p. 7-76.

Figure RO-4 - Operation and Maintenance Labor Cost
Reverse Osmosis

ELECTRODIALYSIS

Electrodialysis (ED) is a method used for the reduction of dissolved solids in feed water which can contain as high as 5000 mg/l TDS. Several municipal installations are already operating in the United States, using brackish well water as feed.

ED uses D.C. electric current to transfer the ionized salts through ion selective membranes. Thus, like reverse osmosis, the energy requirement depends on the concentration of dissolved solids in the feed-water and is proportional to the electrical equivalents of the salts removed from the feed water.

ED units are made up of "cell-pairs," a cell-pair being an anion selective membrane and a cation selective membrane sandwiched between spacers. Several of these cells are assembled in a "stack", between a pair of electrodes.

Thirty to 50% of the dissolved solids in the feed-water will be removed in a single pass through a stack, which has a known maximum flow rate. Therefore stacks must be assembled in parallel to provide increasing flow rates. One set of stacks arranged thus is known as a "stage". Greater percentage removals of dissolved solids can only be accomplished by increasing the number of stages.

Electrodialytic efficiency is severly impaired by the presence of particulate matter, soluble and insoluble organics, iron and manganese and hydrogen sulfide. If these contaminants are present, they must be removed in a suitable pre-treatment train. Electrodialysis membranes can also suffer from mild bacterial attacks, although this is rare. Chlorination in the stack is sufficient to prevent this occurrence.

Given a suitably designed system, electrodialysis is capable of rejecting 70% to 80% of dissolved mineral solids.

ELECTRODIALYSIS PLANT COST CALCULATIONS

In order to determine the capital cost for the ED plant, certain calculations must be made to determine the number of stacks and stages required, since the plant cost is proportional to the extent of these components.

Step 1. Determine the rating factor from Figure ED-1.

Step 2. Determine the minimum number of stages required from Figure ED-2.

Step 3. Verify the number of stages obtained from the above procedure in the following manner:

Compute the fraction of solids remaining after each stage using the formula:

$$FSR = \sqrt[n]{\frac{TDS_p}{TDS_i}}$$

where:

FSR = Fraction of solids remaining after each stage.

n = Number of stages obtained from Figure ED-2 minus 1

FDS_p = Desired mg/l of total dissolved solids in product water.

TDS_i = mg/l of total dissolved solids in feed-water.

Using the fraction obtained, determine from Figure ED-2 if the product water output is within the operating range of 545 to 954 m^3/day. If the product water output is in this range, use this number of stacks per stage to compute the total number of stacks required in the desalting plant. If the product water output is not in the operating range, use the number of stacks per stage obtained from Figure ED-2 to compute the total number of stacks required in the desalting plant.

Step 4. Using the number of stacks per stage from Figure ED-2, and the concomitant stack flow rate, compute the number of parallel stages required for the given flow rate. If the required plant capacity is 15,000 m^3/day, number of stages is 4, and stack flow rate is 954 m^3/day, the number of parallel stages

$$= \frac{15,000}{954} = 15.7 \text{ or } 16$$

Therefore total number of stacks = 4 x 16 = 64

Once the required number of stacks has been computed, construction cost, land requirements and site development costs can be taken from Figure ED-3, 4 and 5.

In addition to the three components of capital cost, annual costs for ED plants include:

i. Membrane Replacement

ii. Power Requirement

iii. O&M labor

iv. O&M supplies

v. Chemicals

Figure ED-6 gives membrane replacement costs. This data is based on actual experience in plants operating in the United States. Power requirements are given in Figure ED-7.

Operating and maintenance labor costs are shown in Figure ED-8.

Operating and maintenance supplies are computed at 1% of construction cost per year.

Chemicals are computed at $13.21 per 1000 m^3.

The volumes of feed-water and brine for a required product volume may be computed from the following equations:

$$\text{Brine to product ratio} = \frac{1 - (TDS_p/TDS_i)}{(900/Ca_i) - 1} \quad \text{greater than or equal to } 0.15$$

where TDS_p + TDS_i are the total dissolved solid concentrations of product water and feed respectively.

Ca_i is the calcium ion concentration in the feed

0.15 is a limitation imposed by chemical and electrical considerations.

To compute the volume of brine

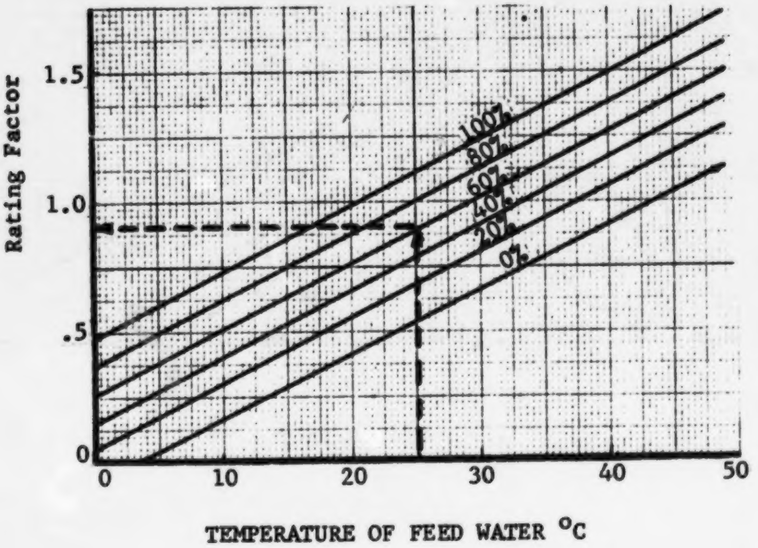
where $V_b = V_p \times BPR$

and V_b = brine volume

and V_p = product volume

and $V_i = V_p + V_b$

where V_i = feed-water volume



Procedure:

Determine percent of TDS represented by Na, K, and Cl in feed water

$$\%TDS = \frac{(Na + K + Cl)\ 100}{TDS_i}$$

where:

TDS_i = ppm TDS of feed-water
Na = ppm sodium in feed-water
K = ppm potassium in feed-water
Cl = ppm chloride in feed-water

Enter chart at temperature of feed-water and read rating factor opposite percent computed above.

Example:

Determine rating factor for a feed water with the following characteristics:

Temperature - 25°C
TDS_i - 3,800 ppm
Na - 1,100 ppm
K - 300 ppm
Cl - 900 ppm

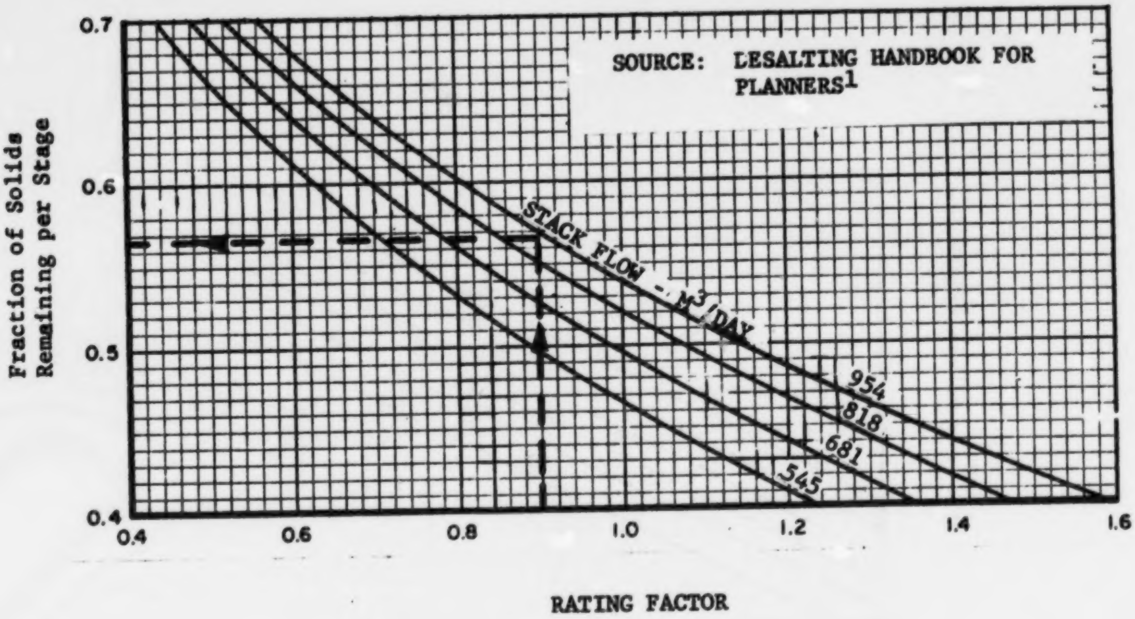
Compute:

$$\%TDS = \frac{(1,100 + 300 + 900) \times 100}{3,800} = 61\%$$

Enter chart at 25°C and read 0.90 as rating factor opposite 61%.

Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972. p. 7-43.

Figure ED-1 - Rating Factor for ED Stacks



SOURCE: DESALTING HANDBOOK FOR PLANNERS[1]

Procedure:

Using the rating factor obtained from Figure ED-1 and the maximum stack flow (954 m^3/day), determine the fraction of solids remaining per stage.

Use this fraction of solids (decimal form) remaining per stage to determine the number of stages required to obtain the desired product water TDS by iteration. The number of iterations required equals the number of stages required.

Example:

Use rating factor determined in previous example (0.9) and read 0.565 as fraction of solids remaining per stage.

If feed-water contains 3,800-ppm TDS and desired product water is 500-ppm TDS, computation of number of stages is:

0.565 x 3,800 = 2,147
0.565 x 2,147 = 1,213
0.565 x 1,213 = 685
0.565 x 685 = 387

The number of stages (or stacks in series) is 4 since 4 iterations are required to obtain the desired 500-ppm TDS in the product water.

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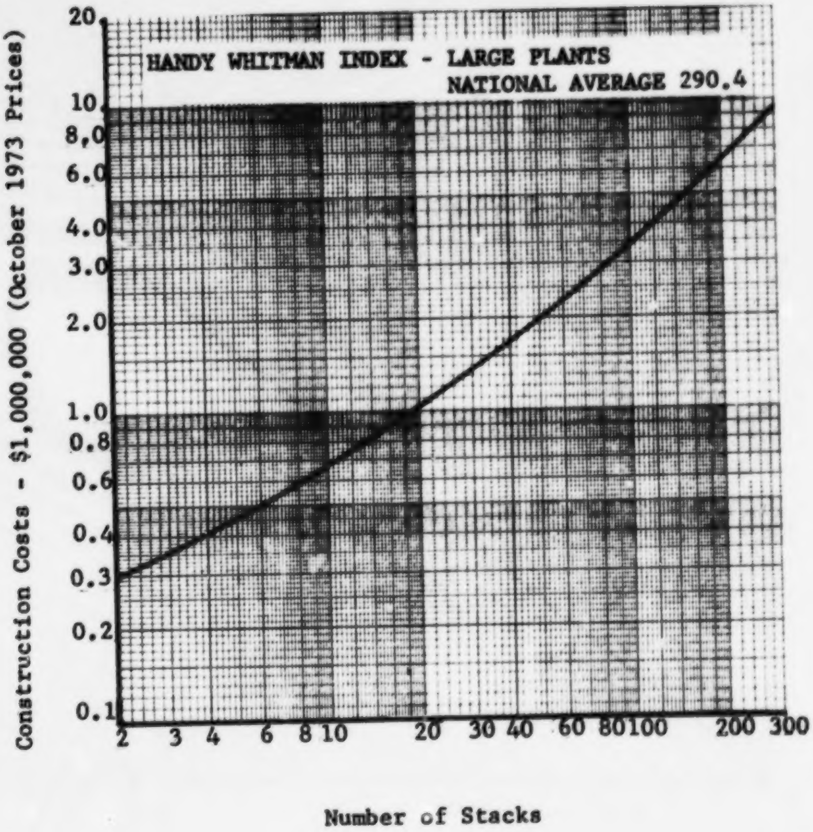
[1] Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972. p. 7-44

Figure ED-2 - Fraction of Solids Remaining Per Stage ED Plants



Construction costs include:

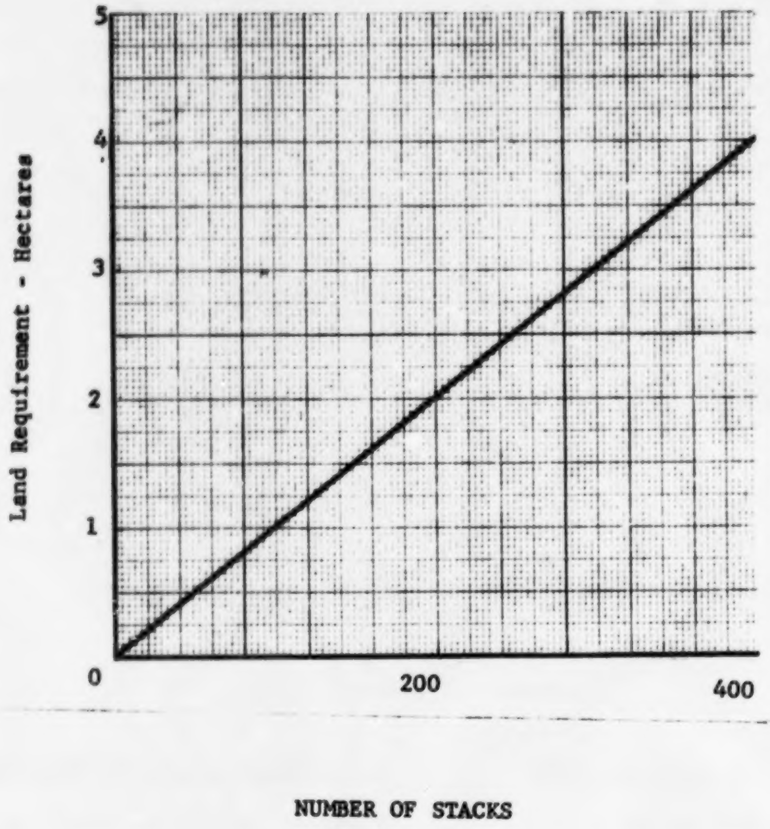
- ED stacks and assembly
- Process pumps and drivers
- Interstack piping
- Electrical process equipment
- Electrical controls
- Foundations
- Designs and specifications
- Construction engineering
- Construction supervision

Construction costs do not include:

- Interest during construction
- Owner's general expense
- Land costs
- Feed water facilities
- Discharge facilities
- General site improvements
- Product water delivery or storage
- Special pretreatment facilities

Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-45.

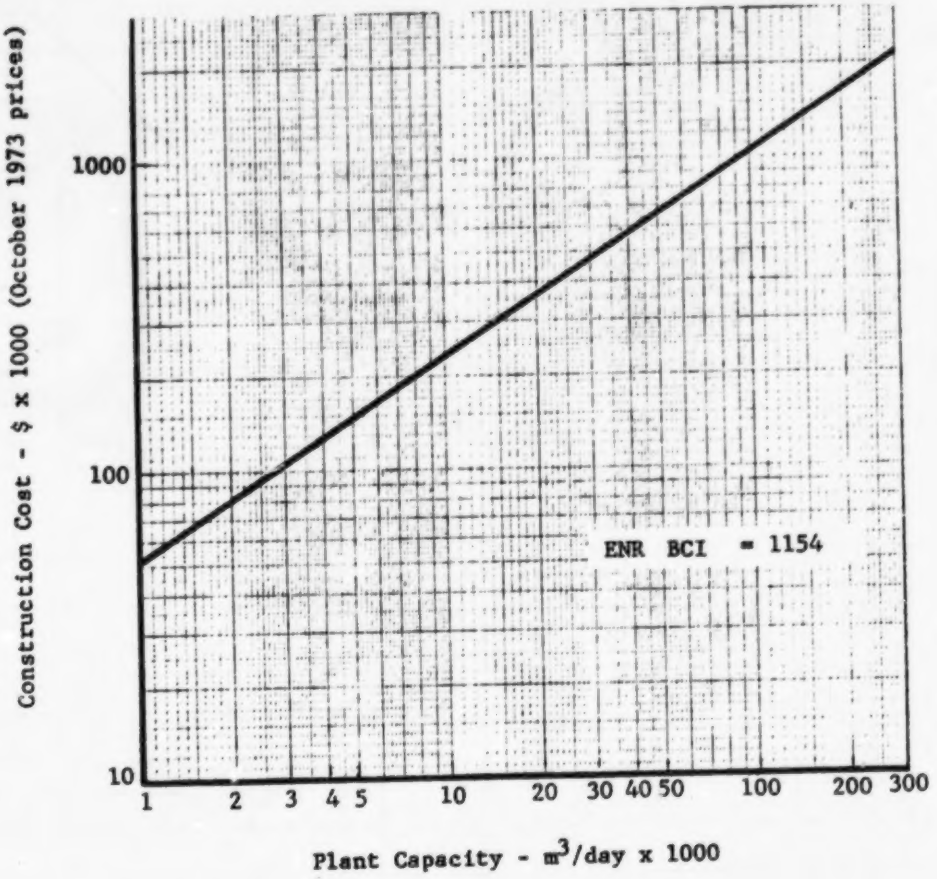
Figure ED-3 - Construction Costs for ED Plants



Source - *Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior*, May 1972, p. 7-52.

Minimum land requirement = .1 hectare

Figure ED-4 - Land Requirements for ED Plants



Includes

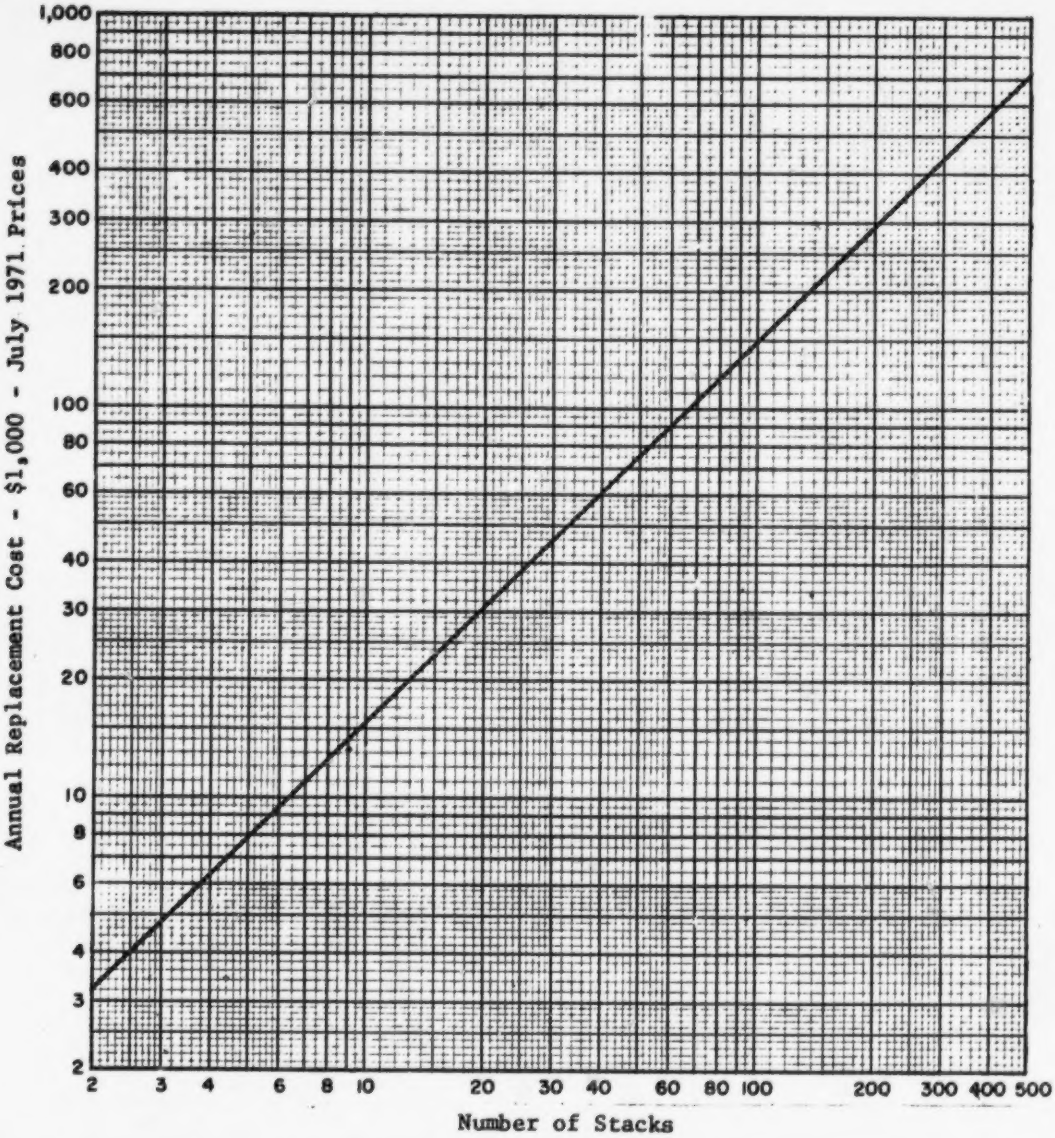
Grubbing, clearing and grading
Roads
Fences and gates
Utilities
Service Buildings
Design and Specifications
Construction Supervision

Excludes

Owner's general expense
Interest during construction
Land cost

Source: Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-57.

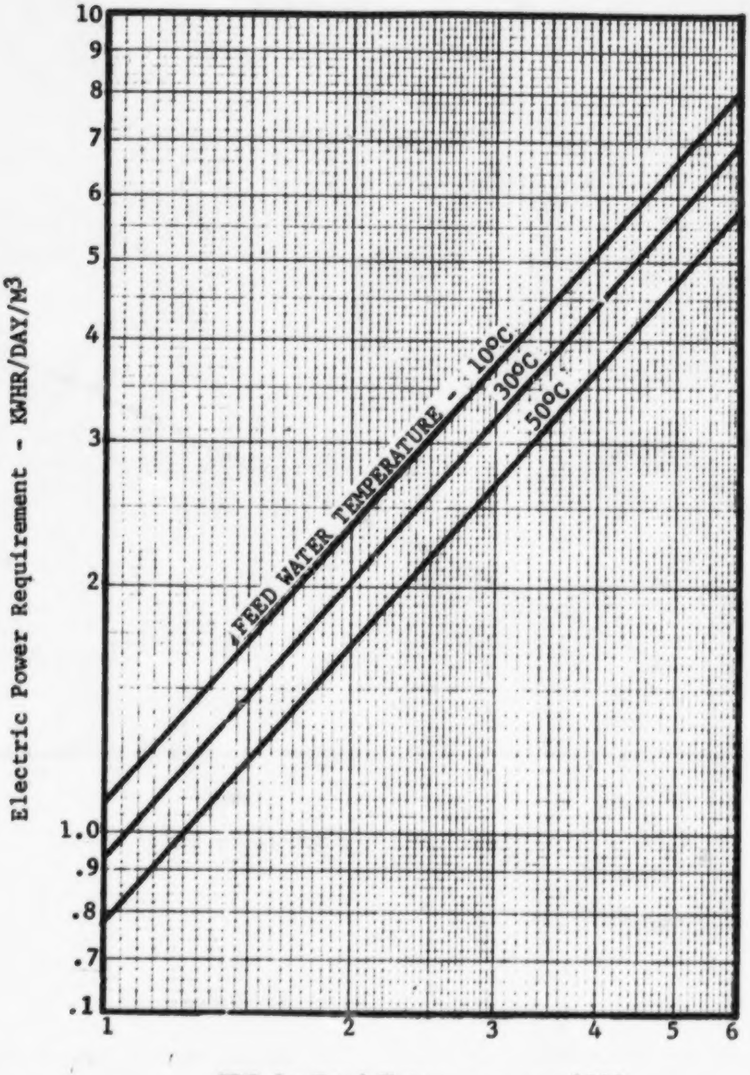
Figure ED-5 - Site Development Costs for E.D. Plants



Replacement costs are based on a membrane cost of $32.3 per square meter and an average membrane life of 5 years. It is assumed that 20 percent of the membranes are replaced annually. It is also assumed that improvements in membranes will offset price increases and therefore cost indexing is not required. There is no easy way to project charges on cost and prices, should be treated on individual project basis.

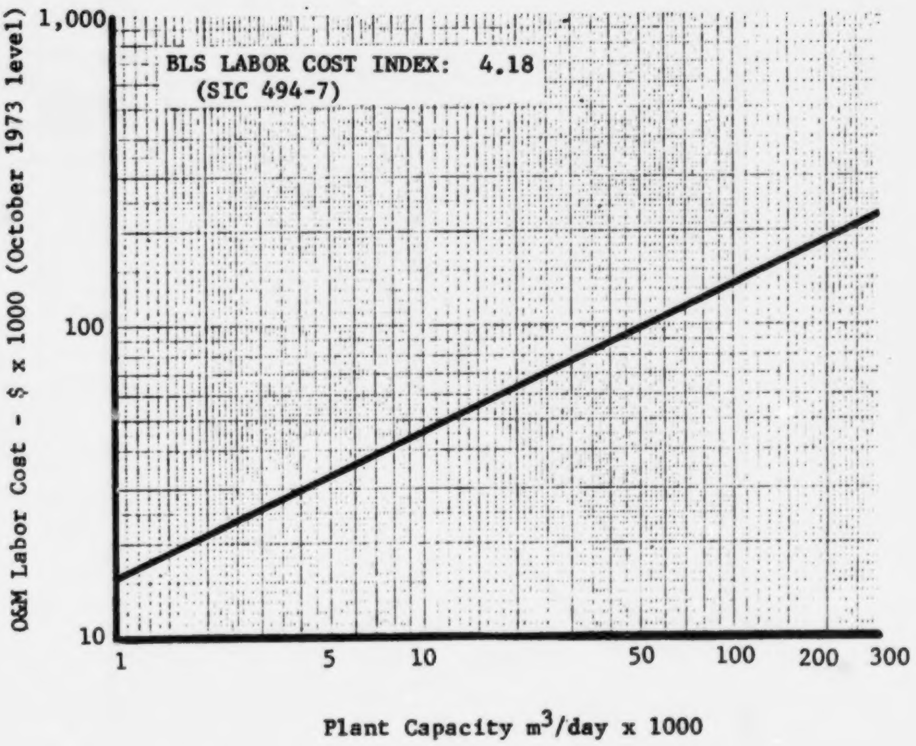
Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p.7-46.

Figure ED-6 - Annual Membrane Replacement Cost



Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-83.

Figure ED-7 - Electric Power Requirements



Includes	Excludes
O&M salaries and wages	Major repair labor costs
Payroll extras	Component replacement labor costs
General and administrative expenses	

Source: Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-76.

Figure ED-8 - Operation and Maintenance Labor Cost
Electrodialysis

DISTILLATION

When water is distilled, dissolved or suspended materials which are not volatilized will remain in the liquid phase.

There are two basic distillation methods in current use. The first and most traditional method is the multiple-effect technique. The evaporators are operated in series, with each evaporator at slightly lower pressure than the previous one. Because of the resultant reduction in boiling point, in the subsequent effects, the steam produced in one effect can be used as the heating medium in the next effect, and so on. This results in good steam economy. A commercial application of this technique is known as the vertical tube evaporator.

A more recent technique known as flash evaporation increases the amount of product per unit of energy input. In this method, the water is heated under sufficiently high pressure to suppress boiling. When the pressure is released, the hot water "flashes" into steam. By controlling the pressure release in stages, internal heat recovery is possible, thus providing good thermal efficiency.

Distillation processes operate at a fixed maximum temperature, although it has been shown that it is economically desirable to operate at higher temperatures. However, in the majority of present day applications, the upper temperature limit is dictated by the scaling tendencies of calcium and magnesium salts found in seawater.

The very fact that hot seawater is used produces an extremely virulent atmosphere for corrosion. It is safe to say that all distillation plants currently operating on seawater in the United States have undergone major repair due to corrosion in a relatively short period of operation.

By and large, the product water from a distillation plant will be very low in dissolved salts, generally 25 mg/1 or less, if seawater is used as the raw water supply. Because of the high corrosive action of pure water, the product is passivated before it is introduced into a supply system.

The application of distillation to the removal of specific contaminants must be regarded as an expensive solution to the problem. In the distillation technology, a large volume of water is removed from a small amount of dissolved material. Thus the energy requirement is fairly constant, as it is based on the amount of water to be evaporated, irrespective of the concentration of dissolved solids. The electrodialysis process, by comparison, removes the dissolved solids from the water, thus making the energy requirement proportional to the solids concentration, rather than the volume of water to be treated.

Distillation operations are generally preceded by deaeration, since dissolved gases in the feed-water are released and become part of the vapor stream. Since they are incondensible, they have an adverse effect on the condensation of the stream and reduce the thermal efficiency of the system. Where feed-water is heavily loaded with suspended organic or inorganic solids, clarification is required. This practice is not generally employed, however, with seawater.

Calcium and magnesium may also be removed if the feed contains concentrations which will provide for heavy scaling under normal operating conditions. Again, seawater distillation does not usually incorporate such pre-treatment.

There are three common types of distillation processes now being specified for desalting drinking water supplies. These are multistage flash (MSF), vertical tube evaporator (VTE), and a combination of multistage flash and vertical tube evaporator (VTE-MSF).

DISTILLATION SYSTEM COST CALCULATION

There are 5 basic cost centers included in computing the annual cost of a distillation plant. They are:

i. Capital Cost

ii. Heat Energy Cost

iii. Electric Energy Cost

iv. O&M Labor Cost

v. O&M Supplies

The capital cost center can be broken up into the following components:

i. Cost of distillation equipment

ii. Cost of land

iii. Cost of general site development

iv. Cost of steam generators

The data required to develop these costs are shown on Figures D-1 through D-4.

Figure D-1 - Steam requirements

Figure D-2 - Land requirements

Figure D-3 - Construction Costs - Distillation Plant

Figure D-4 - General Site Improvement

Other annual costs can be obtained from Figures D-5 through D-7.

Figure D-5 - Annual cost for O&M labor, supplies and maintenance materials

Figure D-6 - Electric Power Requirements for Distillation Plant

Figure D-7 - Fuel requirement for Distillation Plant System Generator

The volumes of feed-water, waste, and product water can be calculated from the following equations.

For MSF, based on calcium concentration in brine

Brine to product ratio $= \dfrac{1-(25/TDS_i)}{(900/Ca_i - 1)}$

where 25 = mg/l assumed in product

TDS_i = mg/l in feed

900 = mg/l assumed as maximum allowable calcium concentration in brine

Ca_i = mg/l calcium in feed

For MSF, based on maximum dissolved solids in brine

$$BPR = \frac{TDS_i-25}{60{,}000-TDS_i}$$

where 60,000 = mg/l assumed as maximum TDS in brine

Select the larger BPR computed from above, and substitute in the following to obtain feed-water volume:

$$V_i = V_p\ (1.20 + BPR)$$

where V_i = feed-water volume in m^3/day

V = product water or plant capacity in m^3/day.

For VTE and VTE-MSF

Compute the BPR based on calcium concentrations, and the BPR based on TDS concentrations from the following:

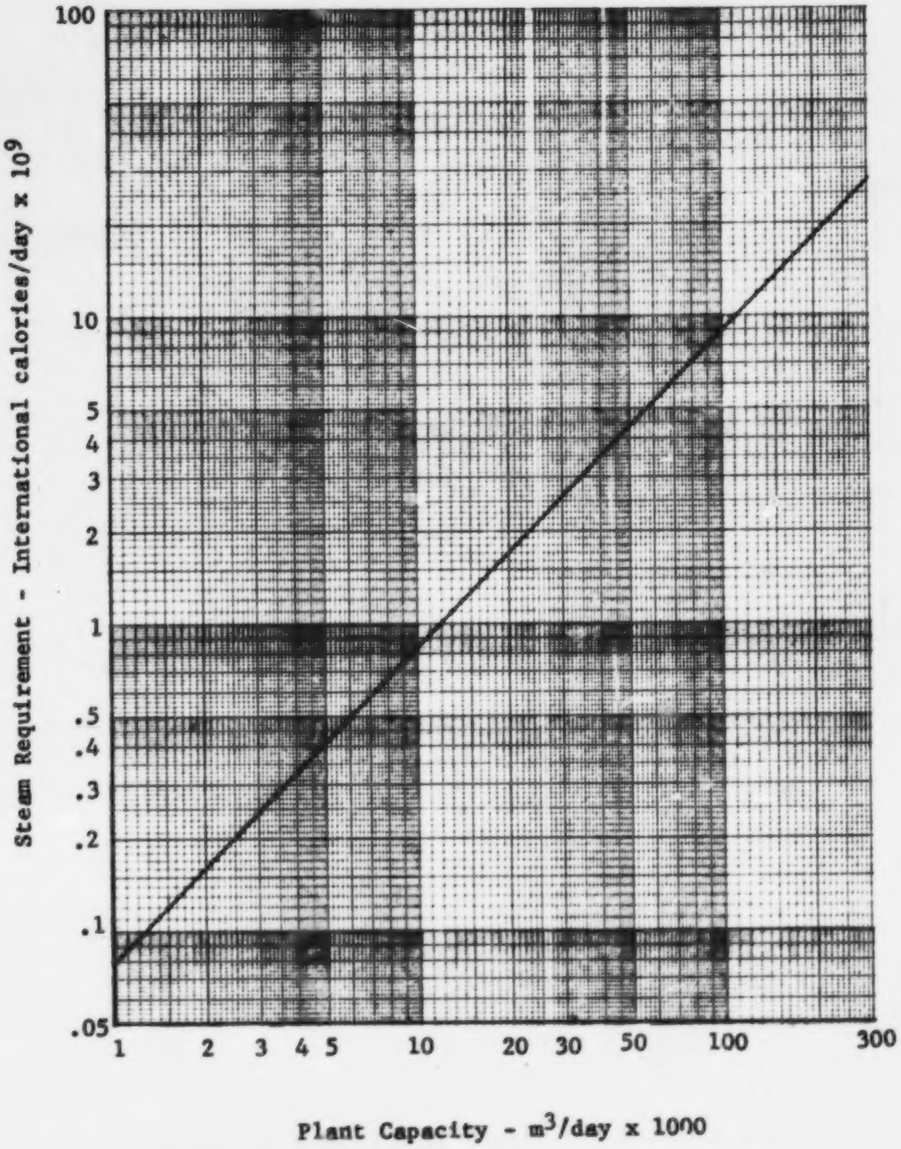
$$BPR = \frac{TDS_i - 25}{80{,}000-TDS_i}$$

Using the larger BPR, the volume of feed-water can be computed using

$$V_i - V_p(1.15+BPR)$$

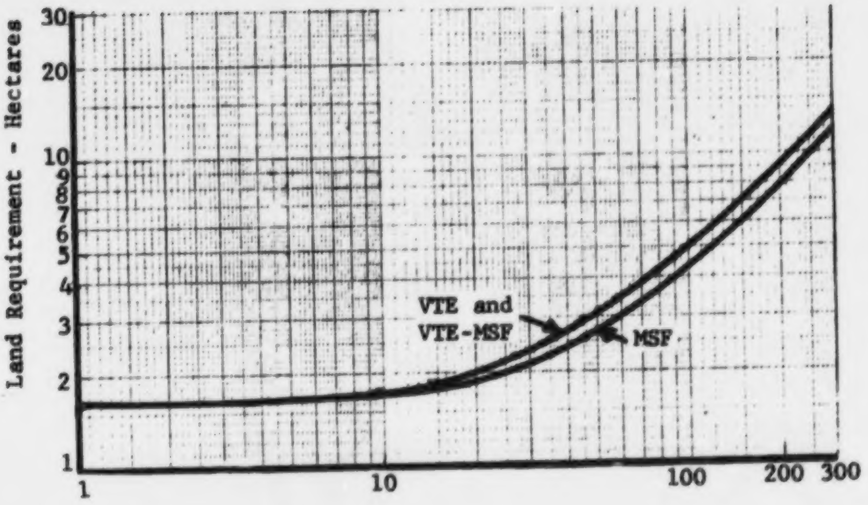
Other recurring costs not shown are:

(a) Chemical costs \$0.005 per cubic meter of product. (BLS index = 104.3 for chemicals and allied products)



Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-81.

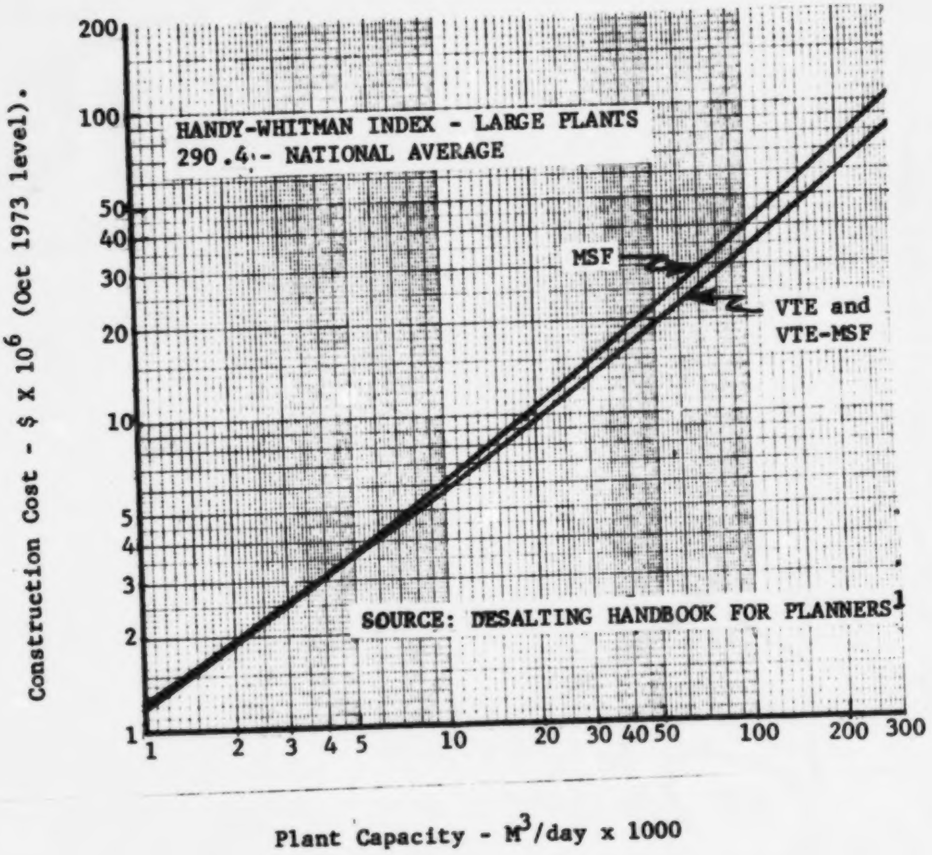
Figure D-1 - Steam Requirements for Multistage Flash (MSF), Vertical Tube Evaporator (VTE) and VTE-MSF Plants



Plant Capacity - m^3/day x 1000

Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972. p. 7-51.

Figure D-2 - Land Requirements for MSF, VTE, and VTE-MSF Distillation Systems, Including Steam Generator Requirement



HANDY-WHITMAN INDEX - LARGE PLANTS
290.4 - NATIONAL AVERAGE

SOURCE: DESALTING HANDBOOK FOR PLANNERS[1]

Construction costs include:

Distillation equipment with internals
Interstage piping
Process pumps, motors, and controls
Degasification facilities
Steam generator and appurtenances
Fuel handling facilities
Designs and specifications
Construction engineering
Construction supervision

Construction costs do not include:

Interest during construction
Owner's general expense
Land costs
Feed water facilities
Discharge facilities
Cooling water facilities
General site improvements
Product water delivery or storage

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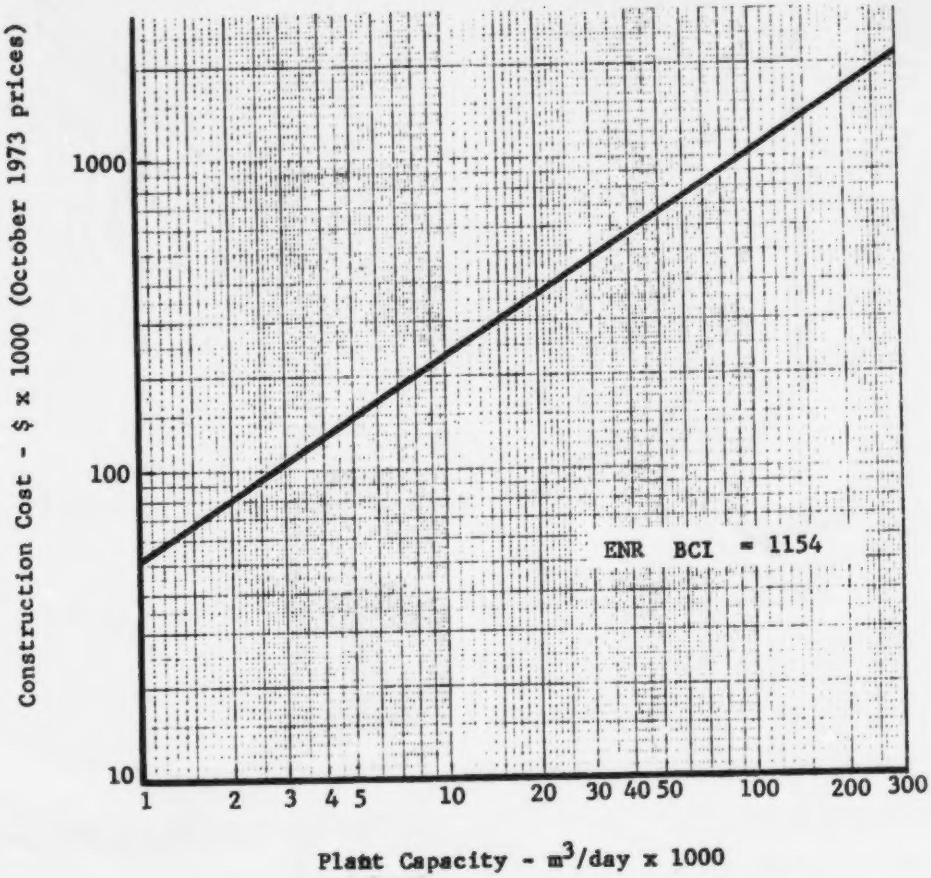
[1] Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972. pps. 7-40, 7-41.

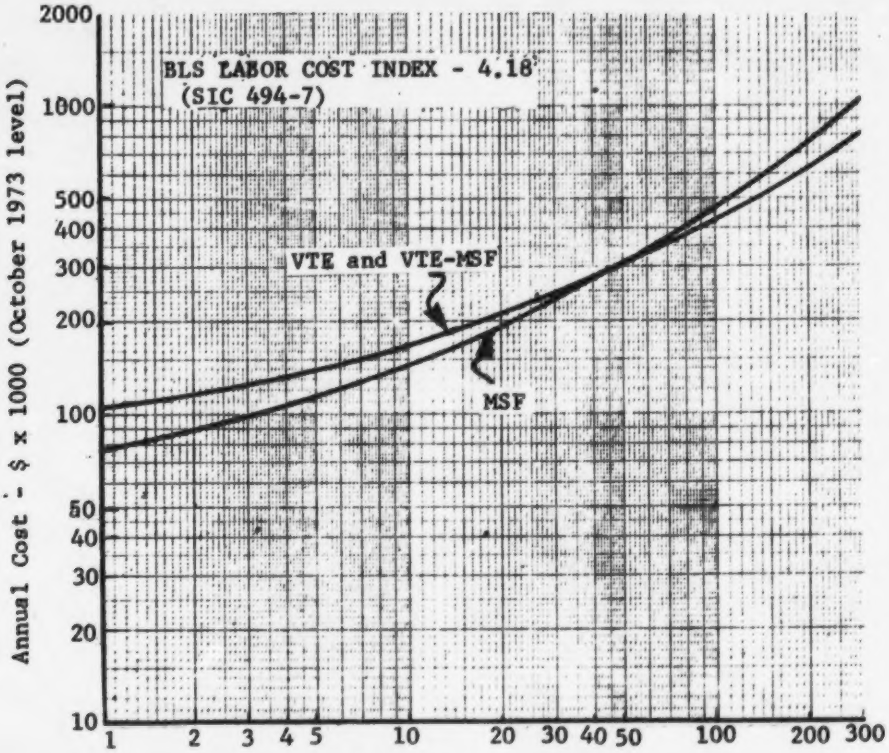
Figure D-3 - Distillation Plant and Steam Generator Construction Cost



Includes	Excludes
Grubbing, clearing and grading	Owner's general expense
Roads	Interest during construction
Fences and gates	Land cost
Utilities	
Service Buildings	
Design and Specifications	
Construction Supervision	

Source - Desalting Handbook for Planners, Office of Saline Water and the the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-57.

Figure D-4 - Site Development Costs for Distillation Plants

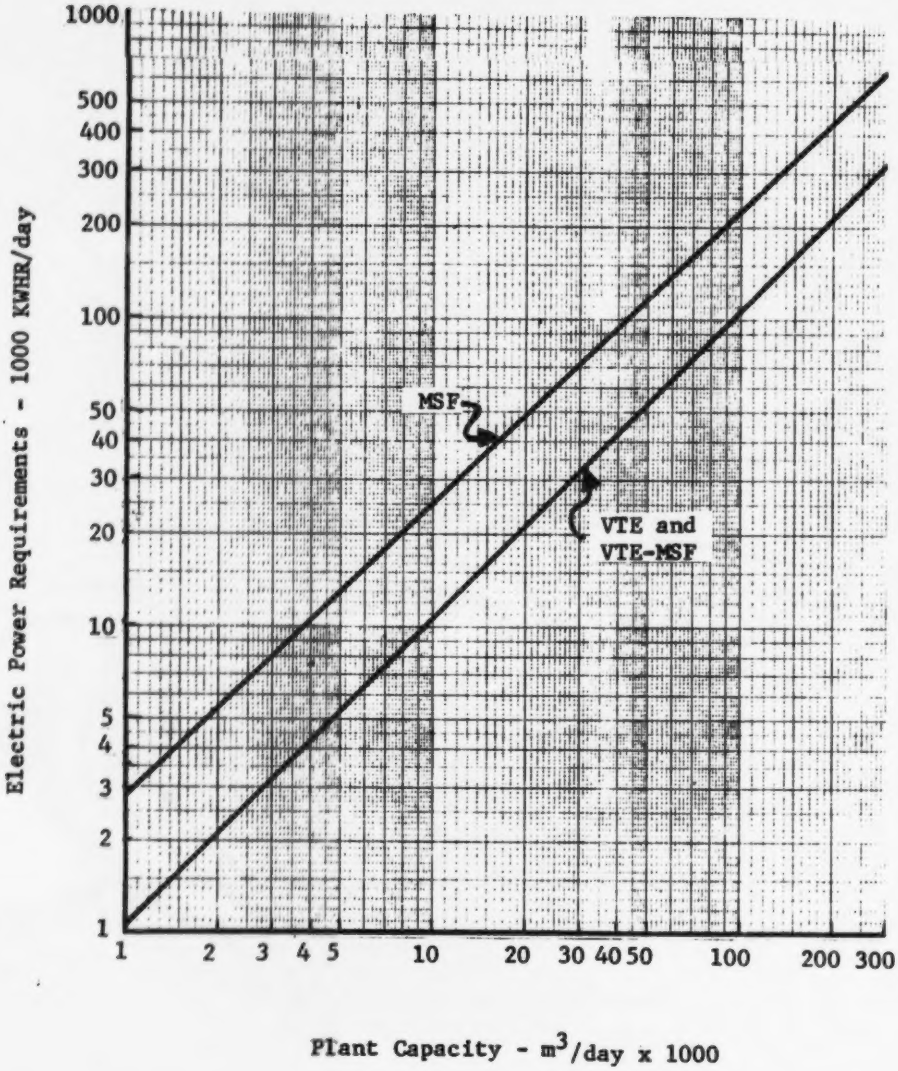


Plant Capacity - m^3/day x 1000

Source - Environmental Planning and Engineering Division.

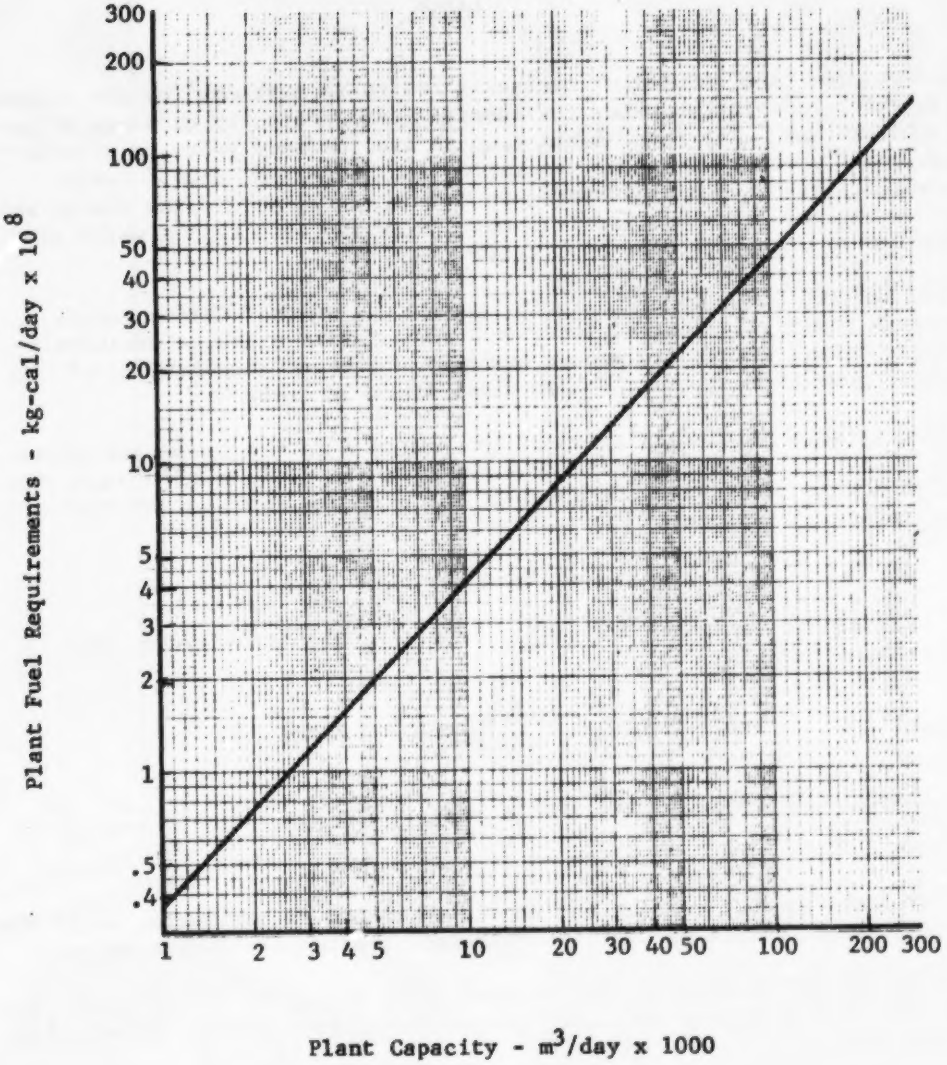
Annual cost included:	Annual cost not included:
O&M salaries and wages	O&M chemicals
O&M supplies and materials	Energy Costs
Payroll extras	
General and administrative expenses	

Figure D-5. Distillation Plant Annual O&M labor cost and Supplies and Maintenance Material Cost



Source - Environmental Planning and Engineering Division.

Figure D-6 - Electric Power Requirement for Distillation Plants.



Source - Environmental Planning and Engineering Division

Figure D-7 - Distillation Plant Fuel Requirement.(for all types)

ION EXCHANGE

This process uses natural or synthetic resins as carriers for the exchange of harmful ions in the water for passive ions located in exchange sites on the carrier. The process has been in use for many years to provide high quality water for steam generation and industrial uses. Resin technology has made many advances in recent years, developing resins which may be regenerated almost stoichiometrically[1] and also resins which are specific to one particular application.

There are two basic types of resin, cation and anion. Cation resins exchange positively-charged ions, and anion resins exchange negatively-charged ions. Within two groups are many different formulations of resin. Some typical examples are shown in Table IX-1.

A good example of the mechanism of ion exchange is the common municipal application of softening. With the cation resin R_c in the hydrogen form the following reaction takes place at the exchange sites on the resin, in preparation for softening

$$R_c\ H + Na^+ \longrightarrow R_c\ Na + H^+$$

The hydrogen is exchanged for sodium. In the exhaustion cycle, the following occurs:

$$2\ R_c\ Na + Ca^{++} \longrightarrow \left.\begin{matrix}R_c\\R_c\end{matrix}\right> Ca + 2\ Na+$$

and

$$2\ R_c\ Na + Mg^{++} \longrightarrow \left.\begin{matrix}R_c\\R_c\end{matrix}\right> Mg + 2\ Na+$$

The hardness ions of calcium and magnesium remain on the resin, while the effluent from the bed is a dilute solution of primarily sodium salts.

If a second bed is added which contains anion resin, in the hydroxyl form, and first bed is in the original hydrogen form, complete demineralization is obtained.

$$R_c\ H + (Na^+ + Cl^-) \longrightarrow R_c\ Na + H^+ + Cl^-$$

$$R_a\ OH + H^+ + Cl^- \longrightarrow R_a\ Cl + (H^+ + OH^-)$$

$$H^+ + OH^- \longrightarrow H_2O$$

The technique can be applied to any inorganic dissolved salts with removals of 90 to 95% in most cases, with the regenerant chemicals needed depending upon the situation and economics.

1. Stoichiometric means chemical equivalancy

TABLE IX-1 - SOME TYPICAL COMMERCIAL RESIN PROPERTIES

Trade Name	Manufacturer	Type	Bead Size (MM)	Theoretical Capacity (Kgr/ft3 resin)	Oper. Cap. (Kgr/ft^3 resin)	Regenerant	Regenerant Level	Ion Specificity	Max Temp	pH Range	Remarks
Amberlite IR 120	Rohm & Haas	Strong Acid Gelular		41	19	H_2SO_4 4% sol'n	5 lbs 66° "Be" per ft^3 resin	All cations	250°F	1.0-14.0	
Dowex MPS/1	Dow Chemical	Strong Acid Macroreticular	0.40-0.50	38.2	17.0	H_2SO_4 5% sol'n	6 lbs 66° "Be"/ft^3 resin	All cations	300°F	1.0-14.0	
Amberlite IRA-68	Rohm & Haas	Weak Base	0.35-0.45	29	17.8	4% NH_3	1 lb/ft^3 100% NH_3	All Anions	170°F	0-7.0	
Dowex CCR-2	Dow Chemical	Weak Acid	0.38-0.46	90	Increases with increase in ratio of H/A	1% H_2SO_4	110% stoichometric	H^+, Ca^{++}	250°F	5-14	Can be regenerated with H_2SO_3 4% sol'n
Amberlite IRA 400	Rohm & Haas	Strong Base Type 1 gelular	0.38-0.45	30.5	11.8	4% NaOH	6 lbs/ft^3 100%	All Anions	140°F	1.0-14.0	Regenerant @ 120°F
Dowex SAR	Dow Chemical	Strong Base Type 11 gelular	0.41-0.48	29.4	23.1	4% NaOH	6 lbs/ft^3 100%	All Anions	105°F	1.0-14.0	
Amberlite IRA-93	Rohm & Haas	Weak Base Macroreticular	.40-0.50	30.5	21.0	4% NH_3	2.7 lbs/ft^3 100% NH_3	Strong Acid	212°F	0.0-7.0	Can be used as organic scavenger w/strong base
Duolite C-25D	Diamond Shamrock	Strong Acid Highly Porous		37	15-25	4% H_2SO_4	2.5-15 lbs H_2SO_4/ft^3 resin	Na^+	230°F	1.0-14.0	Monovalent: Divalent Exceeds 3: 1.
Duolite CC3	Diamond Shamrock	Weak Acid Granular	.42-.54	92	depends on H/A ratio	1% H_2SO_4	100%-120% of theory	Ca^{++} & Mg^{++}	250°F	5-14	Operating capacity in excess of 50 Kgr/ft^3 are possible.
Duolite A-7	Diamond Shamrock	Weak Base Granular		52.5	depends on acid concen-	4% NH_3	2 lbs/ft^3 resin	Strong Acids	104°F	1 - 4	Attacked by oxidizing agents
Permutit	Permutit Co.	Strong Acid	0.45	35	14	2% H_2SO_4	6 lbs/ft^3 resin	Divalent metals		1 - 14	Capacity increase with Mg^{++} concentration
De-Acidite	Permutit Co.	Weak Base Granular			18.5	2.5% Na_2CO_3	3.5 lbs/ft^3 resin	Strong Acids	100°F	5-10	
S-1	Permutit Co.	Strong Base			13.5	4% NaOH	6 lbs/ft^3 resin	All Acids	120°F		

Depending on the source of the feed-water, substantial amounts of pre-treatment may be required. The main concern is preventing dissolved organic materials from being absorbed on the resin. If this occurs, the resin will rapidly lose its exchange capacity and will have to be replaced. The organics cannot be oxidized by chlorine to remove them, since chlorine will oxidize the resin. Activated carbon filters are generally used as pre-treatment. The feed-water must also be essentially free of silt, sand and other suspended materials.

Treated water output from ion exchange systems is generally in the range of 75% to 85% of the feed-water. The balance is used in the regeneration process, being disposed of as waste brine.

Ion Exchange Plant Cost Calculations

Ion exchange (IX) plants must be carefully designed to meet the needs of specific application. Consequently, it is almost impossible to provide cost data which will satisfy all requirements. However, it is possible to calculate IX costs on a general basis, and this data will be sufficient for planning purposes.

There are three major factors to be considered prior to the cost calculation for IX plant. They are:

i. The dissolved solids content of the raw water.

ii. The required product water quality.

iii. The volume of product water required.

When the reduction in total dissolved solids has been computed, the construction costs of the plant can be found from Figure IX-1. Land requirements are shown in Figure IX-2, and general site development costs in Figure IX-3. The data from these three sources comprise the total capital cost for the treatment plant.

Other costs needed to compute the annual cost of ion exchange plant are:

i. Regenerant chemicals (generally sulfuric acid and caustic soda or ammonia).

ii. O&M labor.

iii. O&M supplies.

iv. Power cost.

Regenerant costs are shown in Figure IX-4. The major portion of the cost is for sulfuric acid, which is priced at $40/ton (U.S.). Other sulfuric acid prices will adjust the cost in approximately the ratio of the respective costs.

Annual O&M labor cost is shown in Figure IX-5.
Electric power requirements are shown in Figure IX-6.
O&M supplies are estimated at 1% of construction cost.
Resin replacement cost can be assumed to be 3% of construction cost per year.

The volumes of feed water, product water, product water, and waste can be computed using the following formulas:

$$BPR = \frac{TDS_i - TDS_p}{1000} \qquad (1)$$

where BPR = brine to product ratio

TDS_i = dissolved solids concentration in feed

TDS_p = dissolved solids concentration in product

1000 = conversion factor relating BPR to salinity reduction

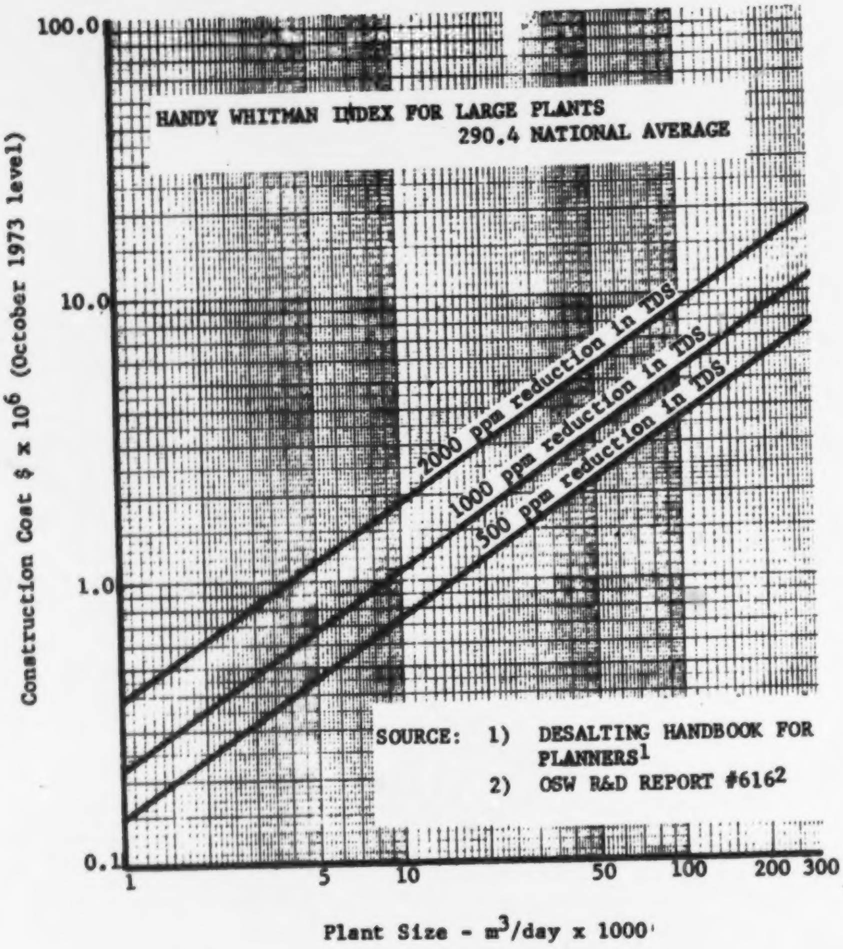
$$V_b = V_p \times BPR \qquad (2)$$

where V_b = brine volume

V_p = product volume or plant capacity

$$V_i = V_p + V_b \qquad (3)$$

where V_i = feed volume



SOURCE: 1) DESALTING HANDBOOK FOR PLANNERS[1]
2) OSW R&D REPORT #616[2]

Construction costs include:

Ion exchange resin beds
Pumps and drives
Connecting piping and conduits
Foundations
Electrical controls
Housing for all equipment
Designs and specifications
Construction engineering
Construction supervision

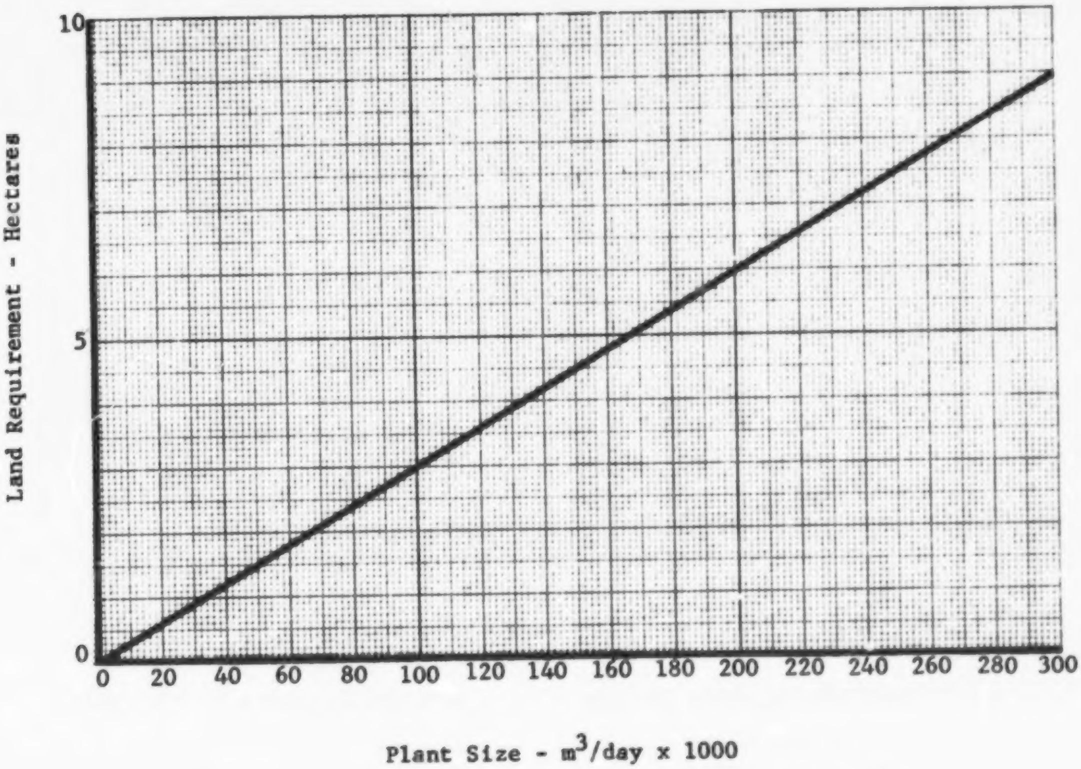
Construction costs do not include:

Interest during construction
Owner's general expense
Land costs
Feed water facilities
Discharge facilities
General site improvements
Product water delivery and storage

[1] Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-49.

[2] Survey of the Ion Exchange Process for Desalination Applications, April, 1970.

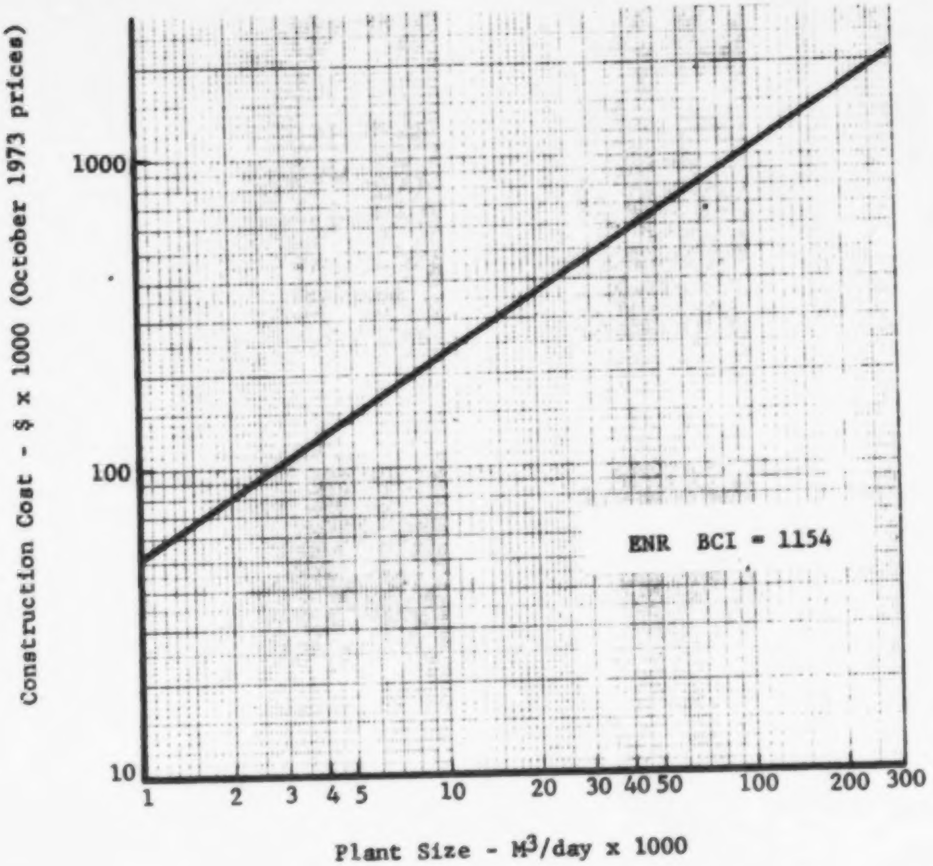
Figure IX-1 - IX Plant Construction Cost



Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-51.

Minimum land Requirement = .1 hectare

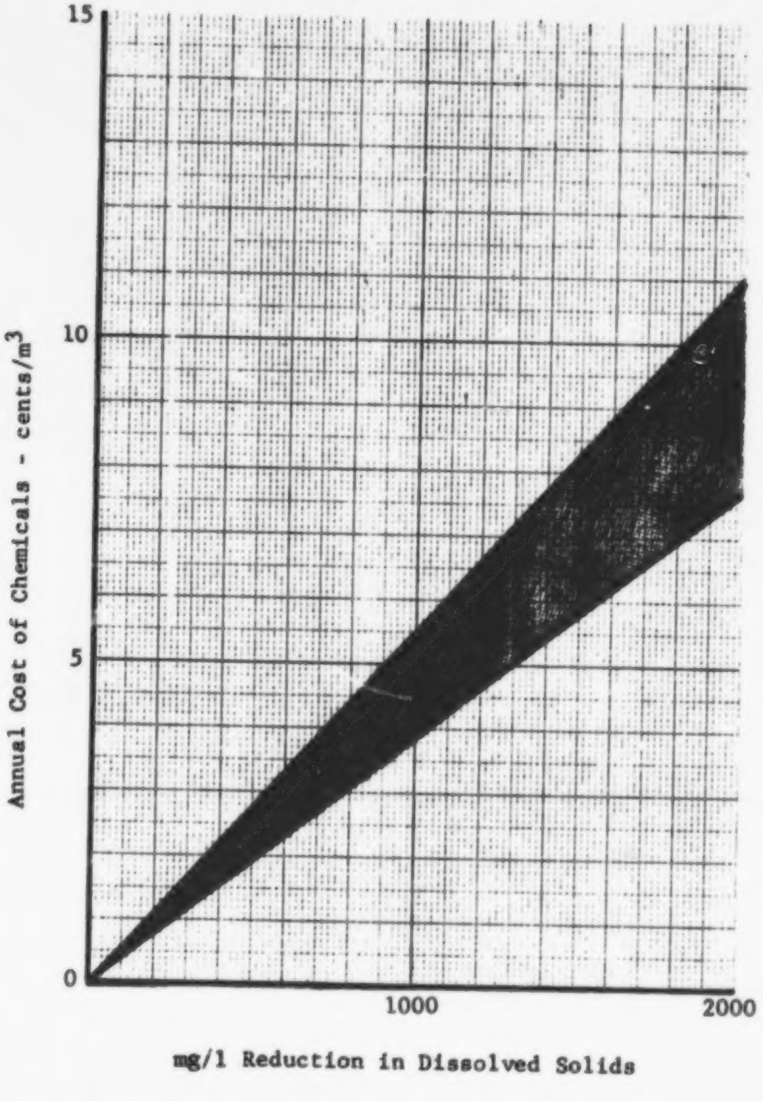
Figure IX-2 - Land Requirements for IX Installations



Includes	Excludes
Grubbing, clearing and grading	Owner's general expense
Roads	Interest during construction
Fences and gates	Land cost
Utilities	
Service Buildings	
Design and Specifications	
Construction Supervision	

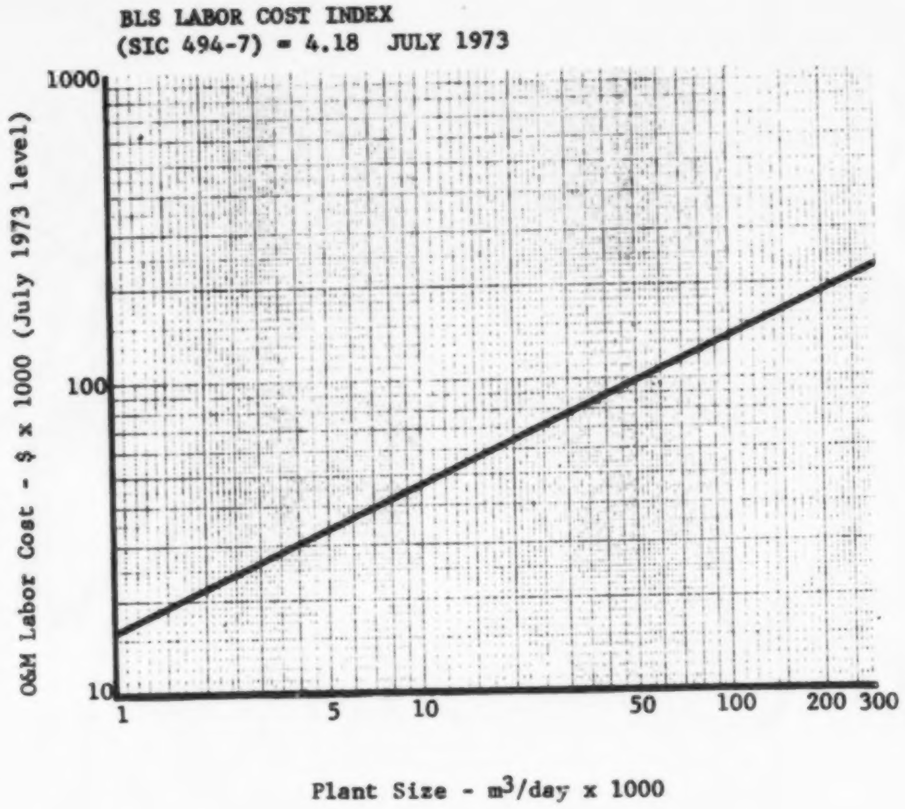
Source - Desalting Handbook for Planners, Office of Saline Water and the the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-57.

Figure IX-3 - Site Development Costs for IX Plants



Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-80.

Figure IX-4 - Approximate Regenerant Cost for IX System



Includes

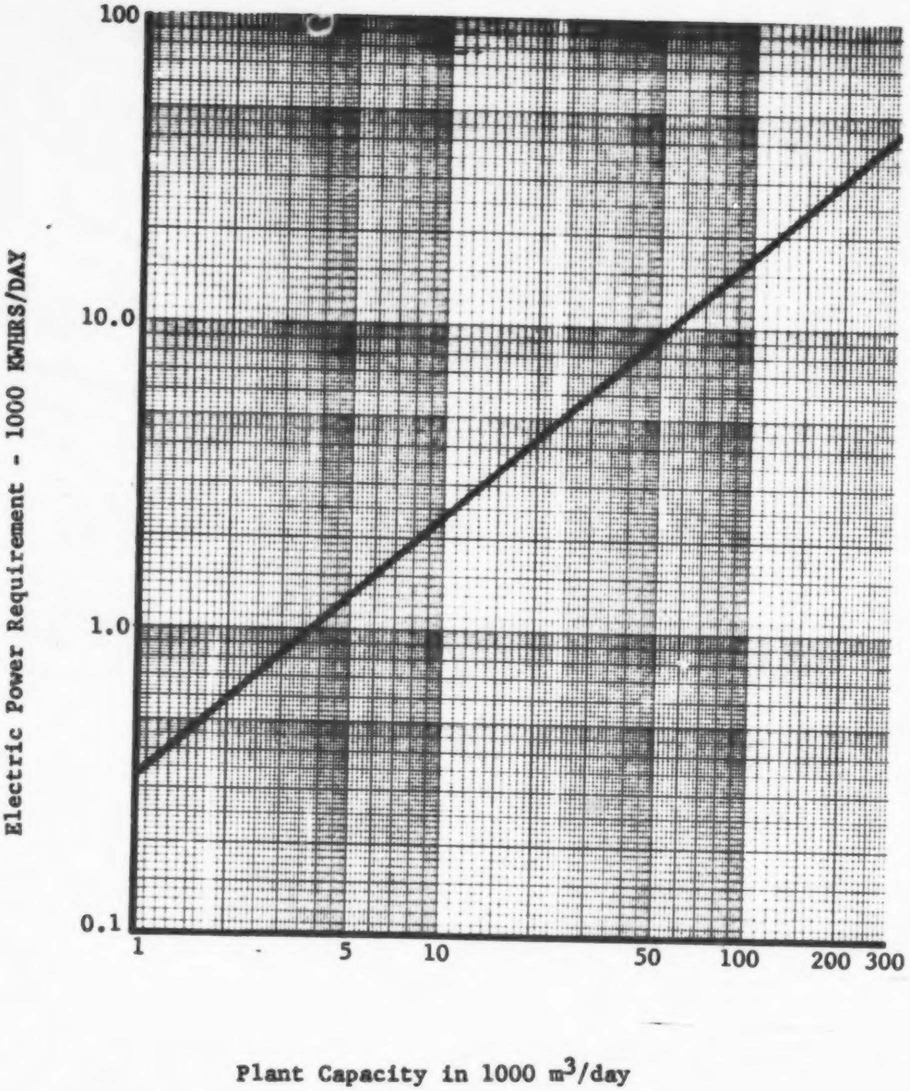
O&M salaries and wages
Payroll extras
General and administrative expense

Excludes

Major repair labor costs
Component replacement labor costs

Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972, p. 7-76.

Figure IX-5 - Operation and Maintenance Labor Cost
Ion Exchange



Source - Desalting Handbook for Planners, Office of Saline Water and the Bureau of Reclamation, Department of the Interior, May 1972. p. 7-85.

Figure IX-6 - Electric Power Requirement for IX System

DISINFECTION

Disinfection of potable water in the United States is accomplished primarily through the use of chlorine, in either gaseous, solid or liquid form. Recently a limited application of ozonation has developed, with excellent disinfection results, but with the drawback that no residual disinfection is available unless post chlorination is used.

a. Chlorination

Chlorination is used in the conditioning of water for potable uses primarily for disinfection purposes. However, chlorine is a powerful oxidizing agent, capable of reacting with both organic and inorganic materials that may be undesirable in a potable supply.

A common concern in municipal water supply operations is the elimination of unpleasant tastes and odors. Many of these are caused by organic materials which are oxidized by chlorination and rendered inoffensive. Hydrogen sulfide gas, extremely soluble in water under atmospheric pressure, occurs in some supplies, imparting the familiar "rotten egg" odor, and causing black metal sulfides to precipitate in some cases. Chlorination provides very rapid oxidation at a pH of about 9, according to the following equation:

$$H_2S + 4Cl_2 + 4H_2O \longrightarrow H_2SO_4 + 8HCl$$

There is a reduction in pH, resulting in the reduction of total alkalinity in the water by about 10 mg/l as $CaCO_3$. Theoretically, 1 mg/l H_2S can be oxidized by about 8.5 mg/l of chlorine. If the concentration of H_2S is high, and fairly constant, the use of chlorine for its destruction will result in a costly operation. However, chlorination will effectively control the H_2S which occurs on a random basis.

Iron and manganese in limited concentrations can also be precipitated as the trivalent hydroxides if the pH is high enough. For manganese the pH must be above 10, and free chlorine must be available. For iron, a pH of 7 or higher is satisfactory, and the reaction can occur with either free or available combined chlorine.

Some dissolved organic materials react with chlorine to produce organic chlorine complexes, most commonly the chlorophenol family. These may impart an unpleasant taste to the water, a situation which can be corrected by activated carbon adsorption, and residual rechlorination.

The most common method in use today of introducing chlorine into the water supply is as a gas, the injection taking place under a vacuum induced by an ejector system operating on the water supply, and mixing the ejector water and chlorine prior to dispersal into the main.

Chlorine gas can be injected directly, but because of its limited solubility, the feed rate is restricted.

In smaller plants, chlorine is fed in the form of a solution of hypochlorite. Two forms of hypochlorite are in common use, calcium and sodium. The solutions are fed by means of chemical proportioning pumps through noncorrosive piping. Generally, the calcium form is shipped as a solid and made up in solution at the use point in quantities small enough to minimize chlorine loss. The solid will also lose chlorine over a period of time, and supplies kept on hand should not be excessive.

Calcium hypochlorite contains at least 70% available chlorine. That is to say, 1.45 kg of hypochlorite in solution provides one kilogram of chlorine for use. Sodium hypochlorite, on the other hand, has only 12% to 15% available chlorine, and is supplied only in liquid form. It is also considerably less stable than the calcium salt, with a recommended shelf life of only 90 days. The calcium form, on the other hand, will lose only 3% to 5% of its available chlorine in a year, under cool and dry storage conditions. However, because of high price, and the necessity for mixing equipment on site, calcium hypochlorite is now used principally for applications where the solid form can be used, such as swimming pools, ornamental ponds, and the like.

A disinfection technique very popular in the 1930's, the use of which has declined of late, included ammonia in the chlorination process.[1] The resulting chloramine complex had the facility of providing a more dependable residual chlorine availability than did chlorine alone, and for that reason achieved widespread popularity.

From an economic viewpoint, chlorine gas is the cheapest method of chlorination. Table DN-1 shows a comparison between the gas, and calcium and sodium hypochlorites, for current market prices.

---

[1] Decline in use is largely due to the advent and development of "free residual chlorination" processes and the realization of the superior bactericidal efficiency of hypochlorous acid. Currently the principal application is post ammoniation to provide long lasting chloramine residuals in potable water distribution systems.

Chlorination Cost - Gas Feed

Since the cost of gas feed equipment is fairly low, debt retirement can be accomplished in a shorter time frame without undue strain on the budget allocated for the water plant. Operating and maintenance labor requirements, and power costs are relatively insignificant. A temperature-controlled building is required, since the feed rate of the chlorine controller is preset, and the gas volume varies with temperature, thus giving under and over chlorination with decreases or increases in temperature.

Figures DN-1 and DN-2 show equipment capital cost and building costs respectively. Land requirement is ignored, since it too is minimal.

Chlorine consumption costs may be computed from the values given in Table DN-2, the applicable unit cost for chlorine gas and the following equation:

Chlorine required in kilograms/day = Plant capacity (m^3/day x mg/l) (from Table DN-2) x (9.98×10^{-4}).

Table DN-1

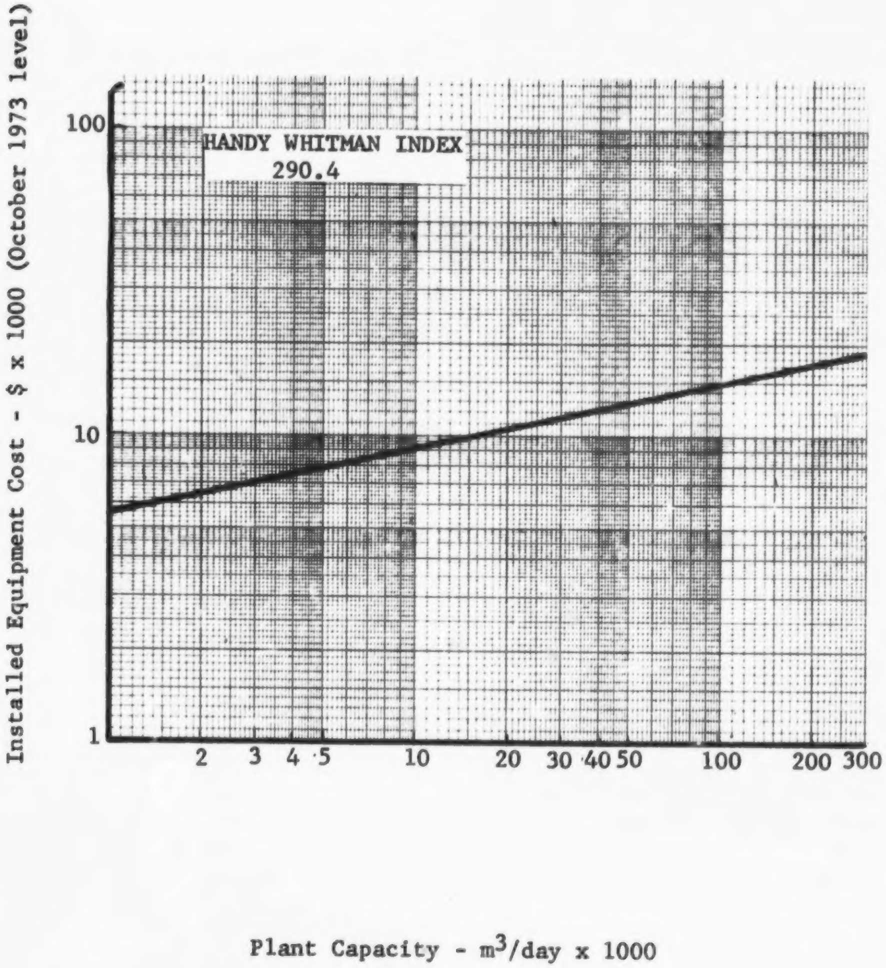
Comparative Chlorine Costs

Source	Available Chlorine	Cost	Cost of Kilogram of Equivalent Chlorine
Chlorine Gas			
(2,000 lb container or 1 carload)	1 kg/1 kg	17¢/kg	17¢
(150-500 Lb cylinders)	1 kg/1 kg	27¢/kg	27¢
Calcium Hypochlorite			
(1 carload)	0.7 kg/kg	44c/kg	63¢
Sodium Hypochlorite			
(5000 gal. tank trucks)	0.9 kg/l	2.4c/l	26.5¢
(55 gal. drums.)	0.9 kg/l	3.8c/l	42.5¢

TABLE DN-2

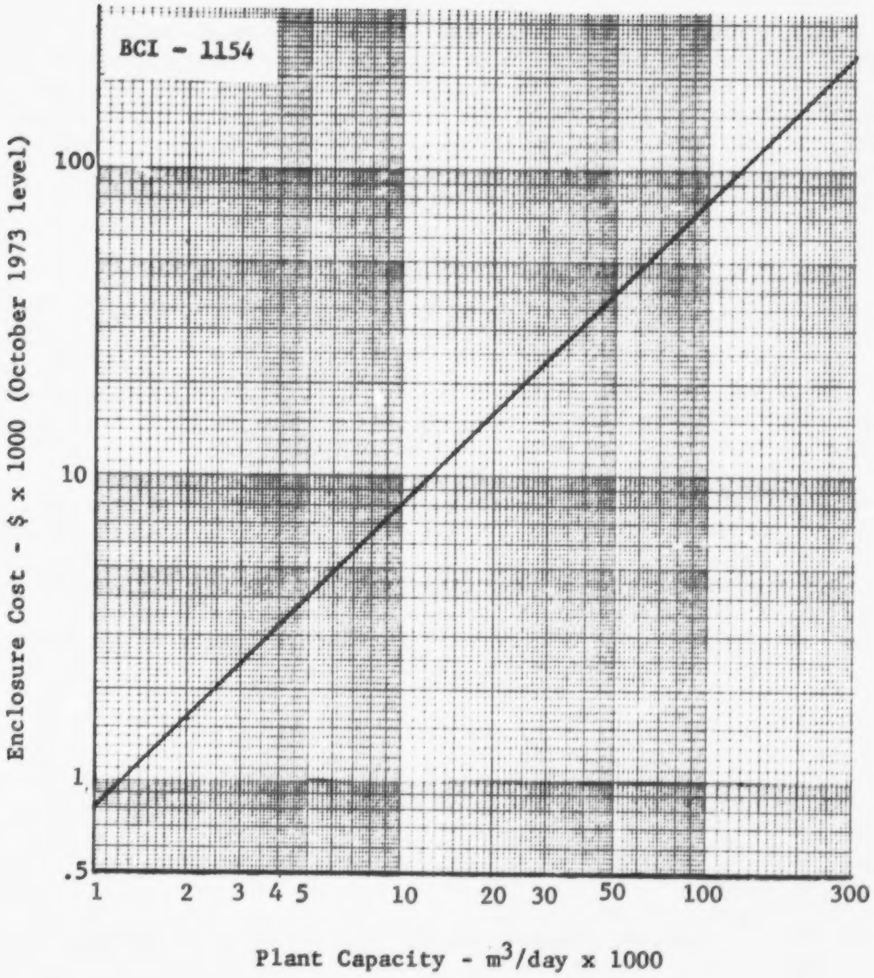
General Guidelines for Cl_2 Dosage Requirements

Chlorination Treatment for:	Typical Dosage Rates (mg/l)
Algae	1-10
Bacteria	1-10
B.O.D. Reduction	5-12
Color	1-10
Cyanide:	
Reduction to cyanate	2 times cyanide content
Complete Destruction	8.5 times cyanide content
Hydrogen Sulfide:	
Taste and Odor Control	2 times H_2S content
Destruction	8.4 times H_2S content
Iron Bacteria:	1-10
Iron Precipitation	64 times Fe content
Manganese Precipitation	1.3 times Mn content
Odor	1-10
Sewage:	
Fresh Raw Sewage	6-12
Septic Raw Sewage	12-25
Trickling Filter Effluent	3-10
Activated Sludge Effluent	2-8
Sand Filter Effluent	1-5
Slime	1-10
Disinfection	25-50
Sulfur Bacteria	1-10
Swimming Pool	1-10
Taste	1-10
Water:	
Cooling	1-10
Chilling	5-25
Washdown	25-50
Well	1-5
Surface	1-10



Source - Environmental Planning and Engineering Division

Figure DN-1 - Chlorination Equipment Cost - Gas Feed



Source - Environmental Planning and Engineering Division

Figure DN-2 - Equipment Enclosure Costs for All Chlorination Processes

Chlorination Costs - Hypochlorite

Hypochlorite systems are of two types. The most common feeds a solution of hypochlorite which is either made up at the pumphouse (calcium) or bought in solution (sodium). Recently, a hypochlorite generator has been developed which operates on the principal of electrolysis. Brine solution or seawater is used as the source of chlorine, the current acting to ionize the components which then react to give sodium hypochlorite. The requirements for the production of one kilogram of hypochlorite are:

power — 6.61 kwh

salt — 3 kg @ 3¢/kg of commercial grade in a 3% solution

Figures DN-3 and DN-4 show costs for sodium hypochlorite equipment and site generator equipment and associated costs. The building costs in all cases are assumed to be the same as shown in Figure DN-2.

The requirement for sodium hypochlorite, which is available only in solution can be calculated from the formula shown previously for computing chlorine requirements, but modified to reflect the chlorine content of the hypochlorite solution. This content varies, but for estimating purposes can be assumed to be 18 kg per cubic meter of hypochlorite solution. The annual cost is therefore the annual volume of hypochlorite solution required multiplied by the local bulk price.

b. Ozonation

Ozonation as a disinfection technique has not received much attention in the United States, for a variety of reasons. These include:

i. There is no residual action the ozone decomposing rapidly to oxygen.

ii. Ozone cannot be shipped and the generation equipment is expensive.

iii. It is power intensive.

iv. Its germicidal action is not progressive as is that of chlorine, but is rapid when the correct dose is applied.

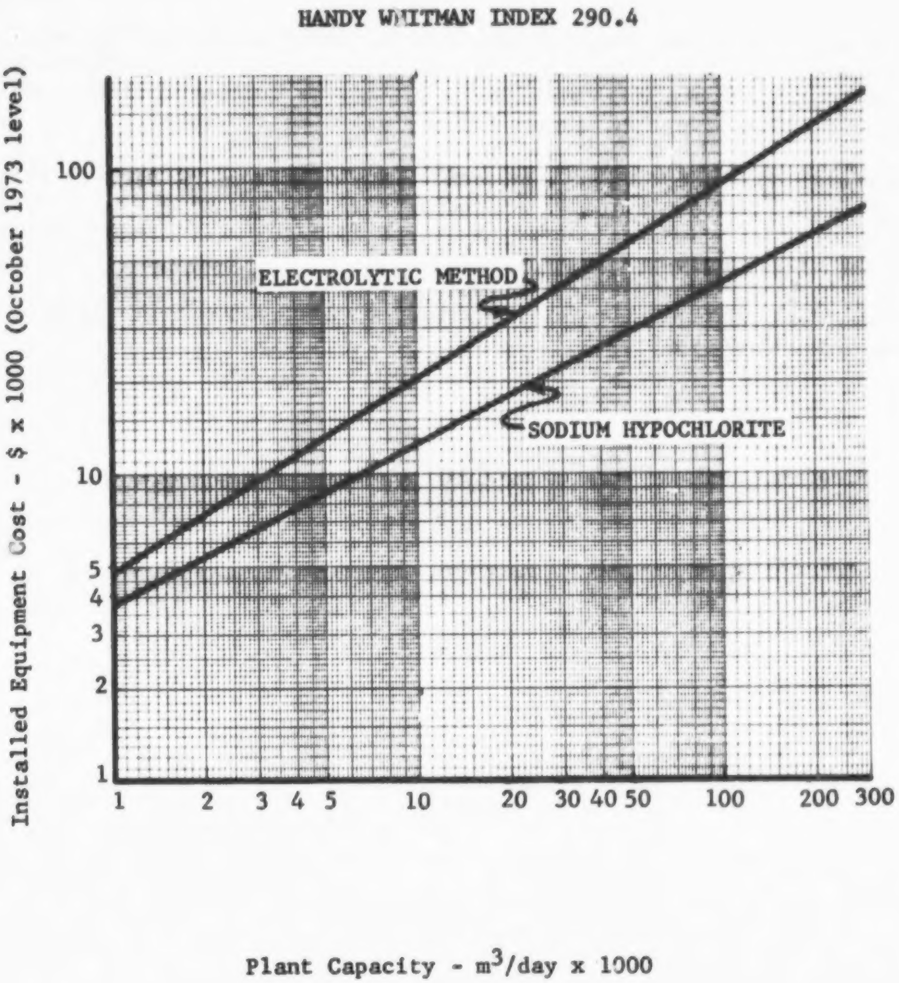
Ozonation has been used for taste and odor control, most prominently in Whiting, Indiana, and Philadelphia, Pennsylvania. In Europe, especially France, ozonation has been used in over 200 plants as a disinfection agent, in many cases for over 50 years.

Ozonation Costs

The primary costs for ozonation are capital costs and operation and maintenance, which is almost all for electric power. Other operating and maintenance costs are inclined to be low, as evidenced at Whiting where such costs averaged about $300 per year for 12 years.

Power requirements for ozone generation ranges from about 4.5 kwh per kilogram to 7 kwh per kilogram of ozone produced depending on the size of the unit, with dosages ranging from 0.5 mg/l to 6 mg/l depending on the quality of the water to be treated.

Figures DN-5 and DN-6 give the construction costs, and power requirements for an ozonation system.



Source - Environmental Planning and Engineering Division

Figure DN-3 - Hypochlorite Disinfection Equipment Costs

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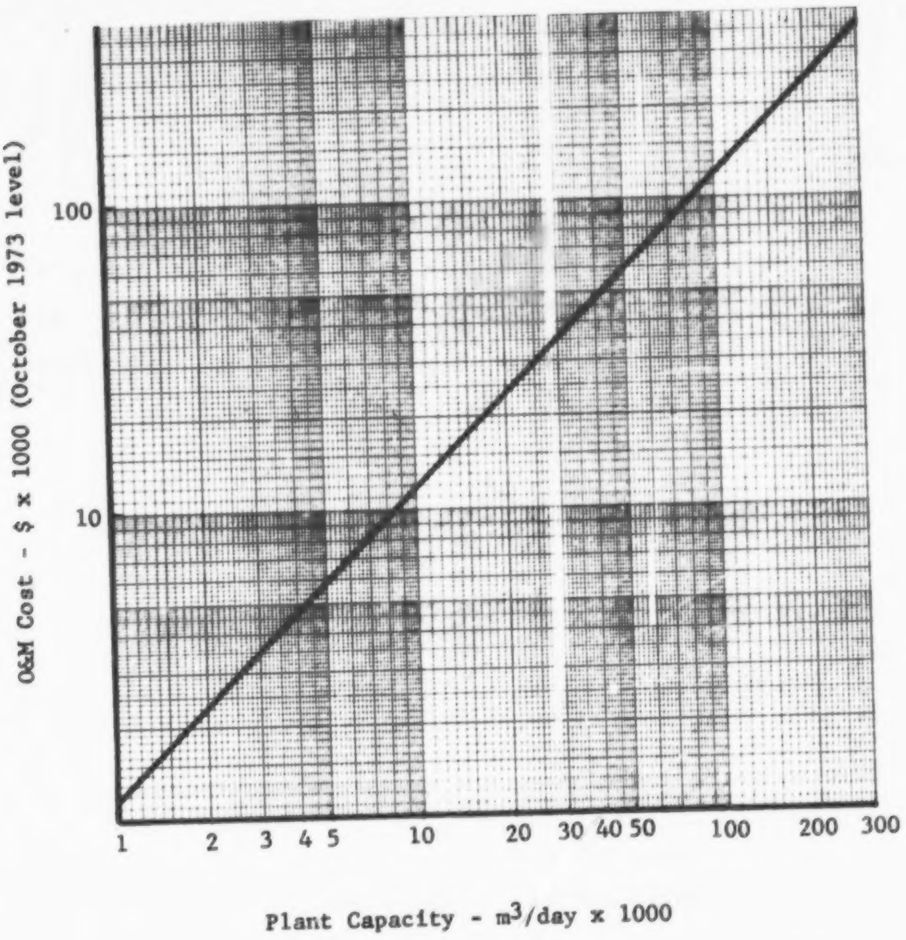
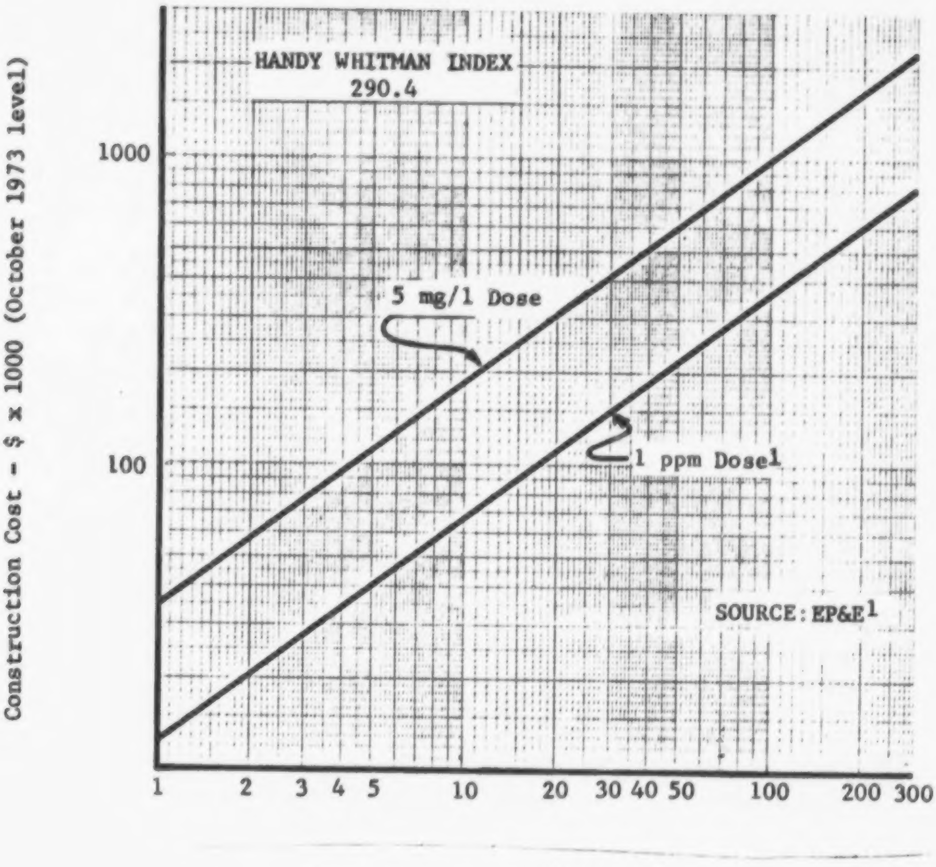


Costs Include

O&M labor
Payroll expenses
Overhead
Regular Maintenance Supplies
  and Materials

Source - Environmental Planning and Engineering Division

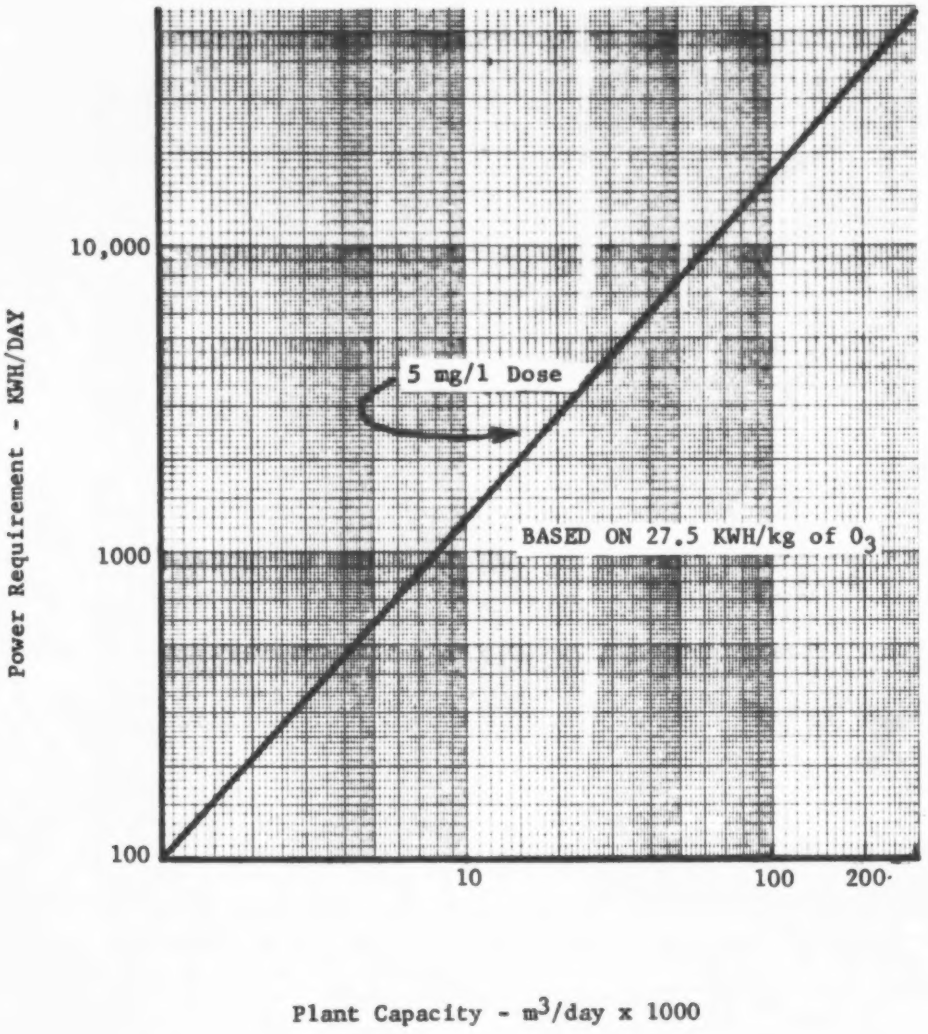
Figure DN-4 - Sodium Hypochlorite Generator O&M Costs



Cost Includes	Cost Does Not Include
Generator (Air-feed)	Land cost (negligible)
Compressor-Dryer	Owner's General Expense
Contractors	Interest during construction
Piping and Controls	
Enclosure	
Design and Specification	
Construction O/H	

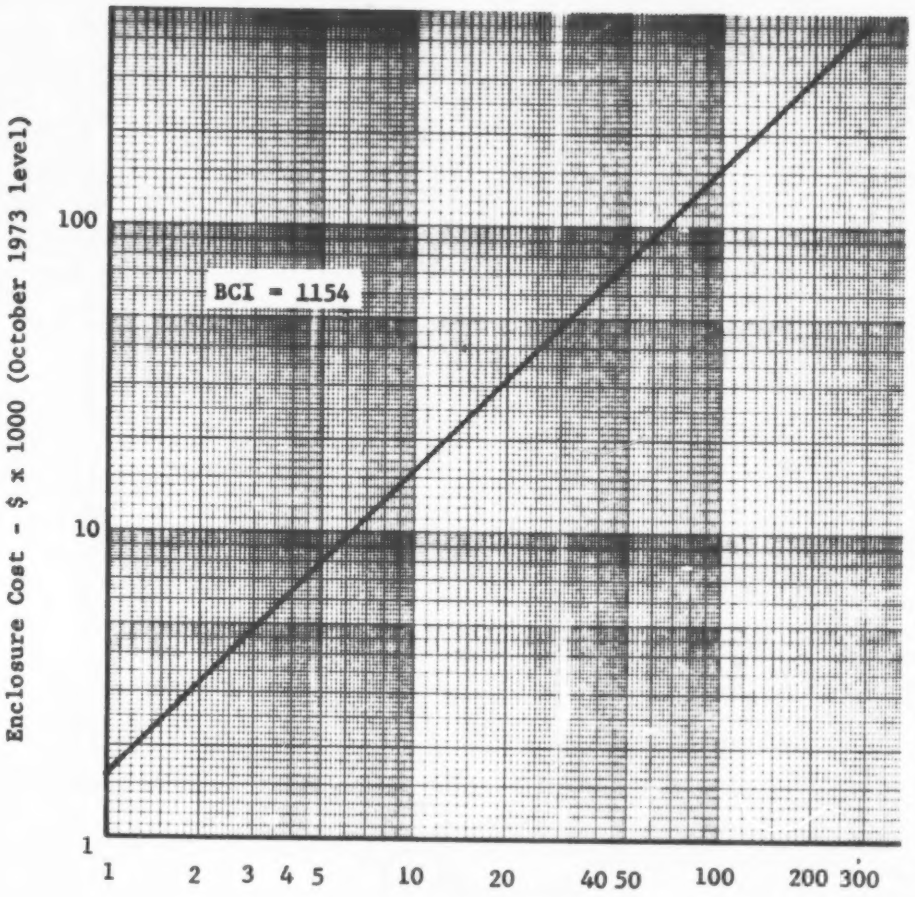
[1] Environmental Planning and Engineering Division

Figure DN-5 - Ozonation System Construction Cost



Source - Environmental Planning and Engineering Division

Figure DN-6 - Power Requirement for Ozonation System



Plant Capacity - m^3/day x 1000

Source - Environmental Planning and Engineering Division

Figure DN-7 - Ozone Generator - Enclosure Costs

MISCELLANEOUS OPERATIONS AND TREATMENT CHEMICALS

a. Activated Carbon and other Taste and Odor Control Treatments.

The occurrence of taste and odor-causing organic materials in ground water supplies is rather uncommon. When they are present, they can readily be eliminated at low cost by chlorination. Surface waters however, present a much broader challenge in terms of taste and odor, and to some extent, color. This challenge can be met by the utilization of activated carbon adsorption.

Activated carbon is used in two forms: as a finely-divided powder, or in a granular form. The powdered form is commonly included as part of the chemical addition in the coagulation process, and is therefore discarded after use along with the alum sludge. Recently the regeneration of powdered carbon has become a commercially viable process, and there are at least two alternate methods available. The economics of regenerating powdered carbon must be carefully examined, since the cost of the virgin material is relatively low, being about one-third the cost of granular material.

If the granular form is employed, there is a definite breakpoint at which regeneration of the material becomes attractive. The choice between granular and powdered carbon is based on the economics involved. If it is less expensive to install the necessary hardware for regeneration of granular carbon than it is to throw away carbon in the powdered form, then the extra capital costs can be justified.

The economics of activated carbon adsorption, assuming that the plant itself has been well-designed and is operating reliably on the design adsorption curve, will depend primarily on the carbon usage rate.

This parameter will be affected by changes in:

i. Flow rate

ii. Impurity concentration in feed

iii. Allowable impurities in effluent

iv. The adsorptive capacity of carbon due to regeneration

v. The type of carbon used.

In addition, the carbon losses in the system must be kept to a minimum. Various research has determined that a carbon loss of 5% to 6% by volume is to be expected.

As in most water treatment unit operations, extensive tests on the water to be treated must be made to determine the optimum volume of carbon to be used in the plant. For planning purposes, considering taste and odor control, a rule of thumb for preliminary equipment sizing is 60 kilograms per 1,000 cubic meters of water. The cost curves given for granular activated carbon treatment are based on this dosage.

For systems using powdered carbon in conjunction with clarification, an average dose rate for planning purposes is 5mg/l. The major costs for this type of carbon treatment are the capital cost for the feeding equipment, and the cost of carbon. Since the cost of the feed equipment is quite small compared to the balance of the clarification system in which it will be incorporated, it may be neglected during planning. The cost of powdered carbon can be assumed to be 20 cents per kilogram (density = 200.4 kg /m^3) or $24.00 per cubic meter, purchased in car load lots. Smaller purchased quantities could cost as much as 30 cents per kilogram.

Other chemicals used in taste and odor control are shown in Table MT-1. The major item in addition to activated carbon is chlorine. This use has been covered in an earlier section, together with ozone. The other chemicals shown on this chart are not widely used in today's water supply industry.

The cost data presented are for activated carbon in the granular form. The capital cost is shown in two parts, namely for the adsorption vessels and associated equipment, and for the regeneration equipment. This is to enable estimates to be made with and without regeneration. Other data presented include O & M costs, carbon makeup requirements, and fuel and electric power requirements for the multiple hearth regeneration furnace.

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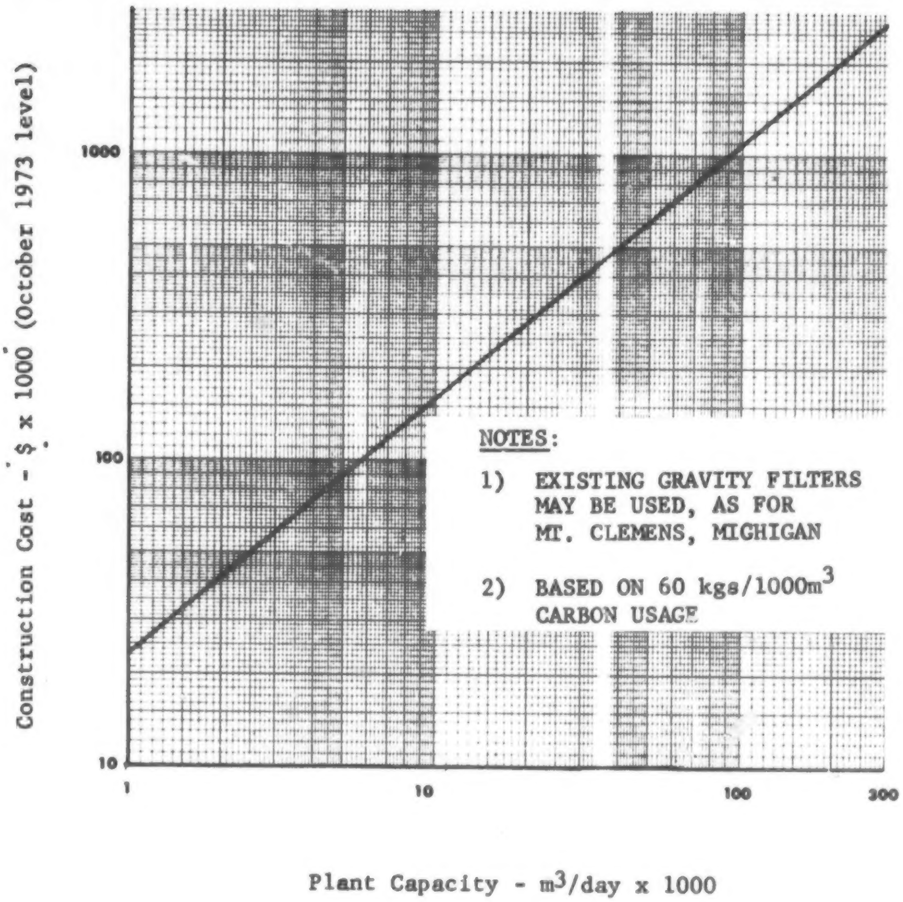

NOTES:

1) EXISTING GRAVITY FILTERS MAY BE USED, AS FOR MT. CLEMENS, MICHIGAN

2) BASED ON 60 kgs/1000m^3 CARBON USAGE

Costs Include	Costs Do Not Include
Steel pressure vessels	Land
Piping pumps	Interest during construction
Instrumentation	Owner's General Expense
Initial Carbon charge	Regeneration equipment
Design	
Construction Supervision	

Source - Environmental Planning and Engineering Division

Figure MT-1 - Construction Cost for Activated Carbon Adsorption

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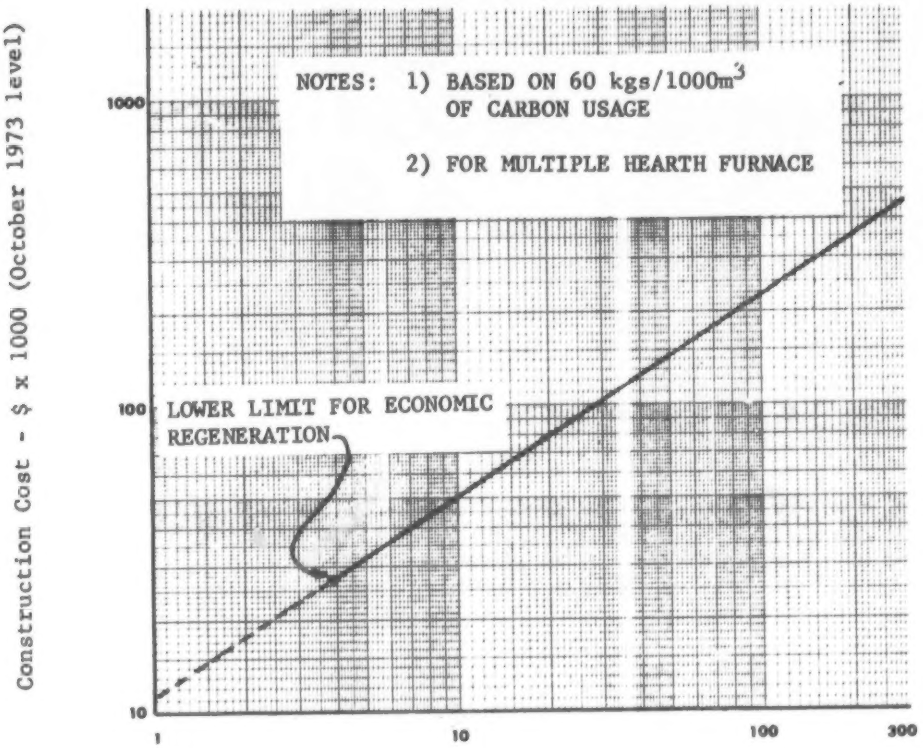

Plant Capacity - m^3/day x 1000

Costs Include	Costs Do Not Include
Regeneration furnace	Land
Pumps, piping	Owner's General Expense
Controls	Interest during construction
Design	Adsorption equipment
Construction Supervision	

Source - Environmental Planning and Engineering Division

Figure MT -2 - Construction Cost for Activated Carbon Regeneration

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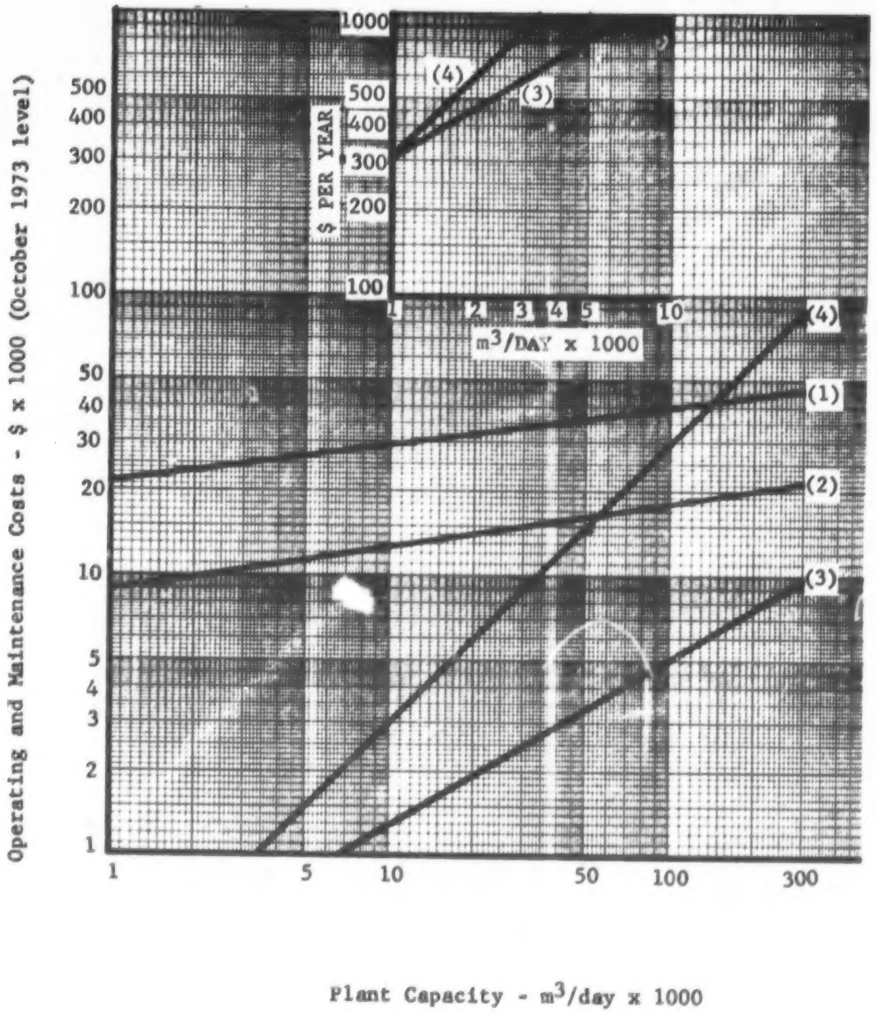

(1) O&M labor - BLS = 4.18 (July 1973)

(2) O&M Supplies and Material

(3) Fuel @ $2.75/million kg-cal.

(4) Carbon replacement @ $0.66/kg.

Source - Environmental Planning and Engineering Division

Figure MT-3 - Operating and Maintenance Costs for Activated Carbon

Table MT-1 - Taste and Odor Control

Chemical name and formula	Common or trade name	Shipping containers	Suitable handling materials	Available forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial strength	Characteristics
Activated carbon, C	"Aqua Nuchar," "Hydrodarco," "Norite"	Bags, bulk	Dry – iron, steel, wet – rubber, silicon, iron, stainless steel	Black granules powder	15	Insoluble (suspension used)		
Chlorine, Cl_2	Chlorine gas, liquid chlorine	100-, 150-lb cylinders, 1-ton tanks, 16-, 30-, 55-ton tank cars	Dry – black iron, copper, steel, wet gas – glass, hard rubber, silver	Liquefied gas under pressure	91.7	0.07 (60 °F), 0.04 (100 °F)	99.8% Cl_2	
Chlorine dioxide, ClO_2	Chlorine dioxide	Generated as used	Plastics, soft rubber (avoid hard rubber)	Yellow-red gas		0.02 (30 mm)	26.3% Available Cl_2	
Copper sulfate, $CuSO_4 \cdot 5H_2O$	Blue vitriol, blue stone	100-lb bags, 450-lb bbls., drums	Asphalt, silicon, iron, stainless steel	Crystal Lump Powder	75-90 73-80 60-64	1.6 (32 °F), 2.2 (68 °F), 2.6 (86 °F)	99% $CuSO_4$	
Ozone, O_3	Ozone	Generated at site of application	Aluminum, ceramics, glass	Colorless gas				
Potassium permanganate, $KMnO_4$	Purple salt	Bulk, bbls., drums	Iron, steel, wood	Purple crystals		Infinite	100%	Danger of explosion on contact with organic matter

Costs:	Activated carbon - granular	\$.60 - \$.70/kg
	powder	\$.20 - \$ .30/kg
	Chlorine	\$.11 - \$ .15/kg
	Chlorine - usually manufactured on site	
	Copper Sulphate	\$.55 - \$ .65/kg
	Ozone - made on site	
	Potassium Permanganate	\$.35 - \$ .45/kg

b. Fluoridation and Fluoride Adjustment

In recent years it has become a fairly standard practice to fluoridate water supplies which carry a low concentration of natural fluorides. The optimum level of fluoride in drinking water appears to be about 1 mg/l. If the level is significantly lower, the incidence of tooth decay is increased. At continuous concentrations above 2 mg/l fluorosis will develop which causes mottling of the tooth enamel, or where fluoride concentrations are extremely high, blackening and pitting of the tooth enamel.

In general, the majority of municipal water sources in the United States have less than the desired value of fluoride. Consequently it becomes necessary to add the chemical until the concentration reaches the range recommended by dental researchers and practioners.

The most common chemicals presently used in the fluoridation of water supplies are shown in Table MT-2. All are available in solid form suitable for dry feeding, except hydrofluosilicic acid. All can be hazardous to human health and corrosive to the environment if not handled safely and intelligently.

Ammonium silicofluoride is a white, free flowing crystalline solid of 100% purity which may be introduced by the dry feeder method. Dust collection equipment must be provided, as on all solid fluoride feeders, since inhalation of the dust can be dangerous. Its cost is relatively high compared to other fluoridation compounds. These are shown in Table MT-3.

The acids, fluosilicic and hydrofluoric, and their sodium salts can be used as fluoridating agents, but only the former and its sodium salt are widely accepted. Produced as a by-product of the fertilizer industry, fluosilicic acid is the cheapest of all the fluoridating chemicals. It is however, very difficult to handle, requiring rubber lined or plastic equipment and piping. In pumps, it tends to break down and deposit colloidal silica in the pump, causing excessive wear. Pumping equipment must therefore be of the oil diaphragm type. Full safety clothing and equipment must be employed at all times when handling fluosilicic acid.

The sodium salt, sodium silicofluoride, is the most commonly used fluoridating agent, in spite of its low solubility and relatively high cost. It can be dry fed or made into solution, but care must be taken when considering the liquid form to provide corrosion-resistant materials for handling.

Of all the municipal water supplies in the United States, only 1200 report fluoride concentrations considerably in excess of the 1962 PHS recommended standard. Of these plants, only 14 use a treatment plant to reduce the fluoride concentration. Capital costs involved in fluoridation are extremely small. All that is required is a chemical metering system, and a small structure. The cost of some fluoridating chemicals are shown in Table MT-2 and 3.

Table MT-2 - Chemicals Used For Fluoridation

Chemical name and formula	Common or trade name	Shipping containers	Suitable handling materials	Available forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial strength	Characteristics
Ammonium silico fluoride, $(NH_4)_2SiF_6$	Ammonium fluosilicate	100- and 400-lb drums	Steel, iron, and lead	White crystals		1.7 (63 °F)	100%	White, free-flowing solid
Calcium fluoride, CaF_2	Fluorspar	Bags, drums, bbls., hopper cars, trucks	Steel, iron, and lead	Powder		Very slight	85% CaF_2 less than 5% SiO_2	
Hydrofluosilicic acid H_2SiF_6	Fluosilicic acid	Rubber lined drums, trucks or R.R. tank cars	Rubber lined steel, PVC	Liquid		Approx. 1.8 (60 F)	Approx. 30%	
Hydrogen fluoride, HF	Hydrofluoric acid	Steel drums, tank cars	Steel	Liquid			70%	Below 60%, steel cannot be used
Sodium fluoride, NaF	Fluoride	Bags, bbls., fiber drums, kegs	Iron, lead, steel	Nile blue or white powder Light Dense	50 75	0.35 (most temps.)	90-98% NaF	pH of 4% solution, 6.6
Sodium silico fluoride Na_2SiF_6	Sodium silicofluoride	Bags, bbls, fiber drums	Iron, lead, steel	Nile blue or yellowish-white powder	72	0.03 (32 F), 0.08 (72 F), 0.12 (140 F)	98% Na_2SiF_6	pH of 1% solution, 3.5

Approximate bulk costs:

Ammonium fluorsilicate: 50¢/kg
Calcium fluoride: 8¢/kg
Hydrofluorsilicic acid: 5¢/kg (23% solution)
Hydrogen fluoride: 45¢/kg
Sodium fluoride: 51¢/kg
Sodium silicofluoride: 32¢/kg

Table MT-3 - Equivalent Cost of Fluoridation Chemicals.

Chemical & Commercial Purity	Formula	Wt. % Flucride	Chemical Cost	Equivalent F Cost
Ammonium Fluorsilicate 100%	$(NH_a)2SiF_6$	53	50¢/kg	94¢/kg
Calcium Fluoride 97% *	CaF_2	49	8¢/kg	17¢/kg
Hydrofluosilicic acid 23%	H_2SiF_6	79	5¢/kg	28¢/kg
Hydrogen fluoride 70%	HF	95	45¢/kg	68¢/kg
Sodium fluoride 90%	NaF	45	51¢/kg	$1.26/kg
Sodium silicofluorite 99%	Na_2SiF_6	61	32¢/kg	53¢/kg

* Calcium fluoride is not used in the U.S. but is used extensively in European countries.

There are three generally acceptable methods of fluoride removal that will reduce the levels to below the proposed standard. These are:

1. Adsorption, using bone char or activated alumina
2. Alum coagulation
3. Lime/soda softening, using crushed dolomite limestone.

The activated alumina process is an adsorption system in which the raw water passes through a bed of activated alumina until the fluoride breakthrough occurs. At this point, the bed must be regenerated by a dilute caustic soda solution followed by an acid rinse to neutralize the caustic remaining in the alumina.

A plant operating on this principle was installed at Bartlett, Texas, to treat a water containing about 8 mg/l fluoride. The plant, which contains 20 cubic meters of alumina, can treat about 400 cubic meters of water between regenerations, giving the bed a capacity of about 64.3 grams F/m^3. An interesting aspect of this process is that the alumina capacity for fluoride is proportional to the concentration of fluoride in the raw water, rather than on the level of regeneration, as with ion exchange. The higher the level of fluoride, the greater the sorptive capacity. For instance, at Bartlett, the following capacities were obtained:

- Influent - 8 mg/l; Effluent - 1 mg/l; Capacity 64.3 $grams/m^3$
- Influent - 3 mg/l; Effluent - 1 mg/l; Capacity 42.87 $grams/m^3$

A plant using bone char as the adsorptive media was installed at Britton, South Dakota, in 1948. The operation of the plant was successful, once the proper char material was established. The plant, now shut down, reduced the fluoride concentration from approximately 7 mg/l to below 1.5 mg/l. At 1% solution of caustic soda was used for regeneration, approximately four bed volumes being required, and the bed was then neutralized using diluted sulphuric acid or CO_2. (Sulphuric acid tends to dissolve bone char? consequently this step was very closely controlled).

Later work by Bellack, during arsenic removal studies, showed that use of bone char as the media for defluoridation resulted in poor performance when arsenic was present. Further study indicated that arsenic effectively poisoned the char, rendering it useless for fluoride adsorption. The experiments went on to show that activated alumina is effective in removing both arsenic and fluoride.

The activated alumina charge for the Bartlett plant would cost approximately $5,000 with an estimated rate of 10% per year replacement. Chemical costs for regeneration were given by the operator as being $\$13.20/1000m^3$. This cost is a function of the fluoride removal capacity and in this case can be reduced to $\$6.60/1000m^3/mg/l$ fluoride removed.

For a gravity flow plant using bone char as the adsorption media, the initial equipment costs and regneration chemical costs are somewhat less than for activated alumina but the media replacement rate is greater. For the pressure system, as used in Britton, S.D., initial cost would be more than for the gravity system because of the increase in engineering complexity and higher equipment costs for vessels and pumps.

Figure MT-4 shows the construction costs for both alumina and char plants. Figure MT-5 shows the annual cost of chemicals and media replacement, and MT-6 gives operating and maintenance costs.

The costs for alum coagulation and lime soda softening are given in their respective sections of the report.

Table MT-4 - Comparison of Activated Alumina and Bone Char Facilities

Data Item	Bartlett, Texas	Britton, S.D.
Bed material	Activated alumina	Bone char
Bed volume	20 m^3	12 m^3
Water flow rate - single run capacity	5,677,500 liters*	3,785,000 liters
Fluoride removal	2 mg/l average*	4.2 mg/l average
Vessel type	Gravity	Pressure
Regenerants	$NaOH/H_2SO_4$	$NaOH/H_2CO_3$
Medium size	30-50 mesh	30-50 mesh
Attrition rate	1%/year	1%/year

*Originally removed 7 mg/l with a single run capacity of 3.785 MLD - Source changed to a well with 3 mg/l.

The installed cost of the Bartlett plant was $11,360 in 1951, while the cost of the Britton plant was $10,745 in 1947. Escalating these costs to 1973, using an average of 6% per year:

	Original Cost	1973 Replacement Cost
Bartlett (1951)	$11,360	$40,900
Britton (1947)	$10,745	$45,800

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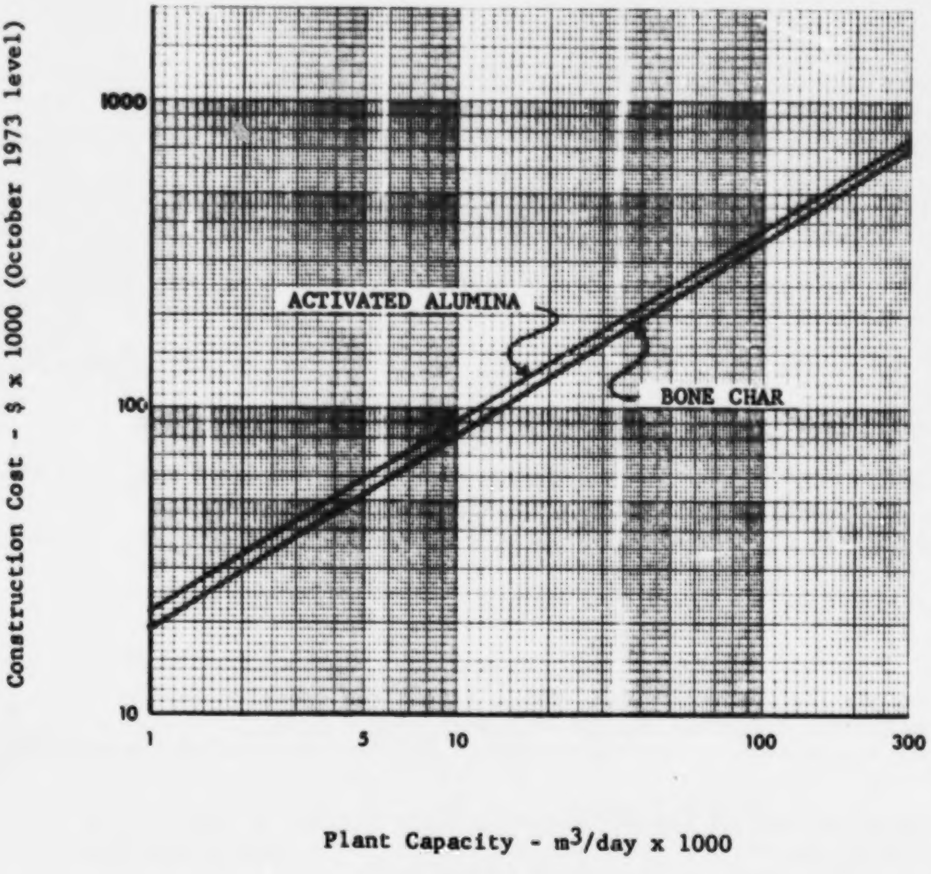
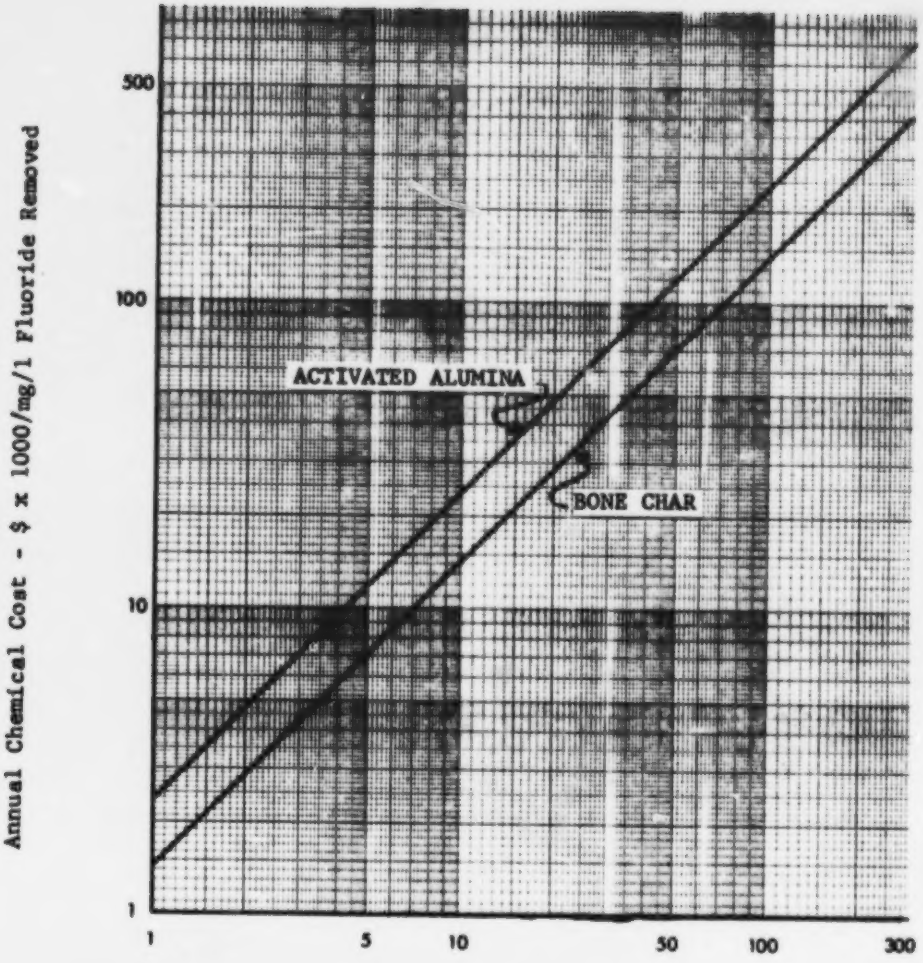


Source - Environmental Planning and Engineering Division

Figure MT-4 - Construction Cost For Two Types of Defluoridation Plant



Source - Environmental Planning and Engineering Division

Figure MT-5 - Annual Chemical and Media Replacement Cost

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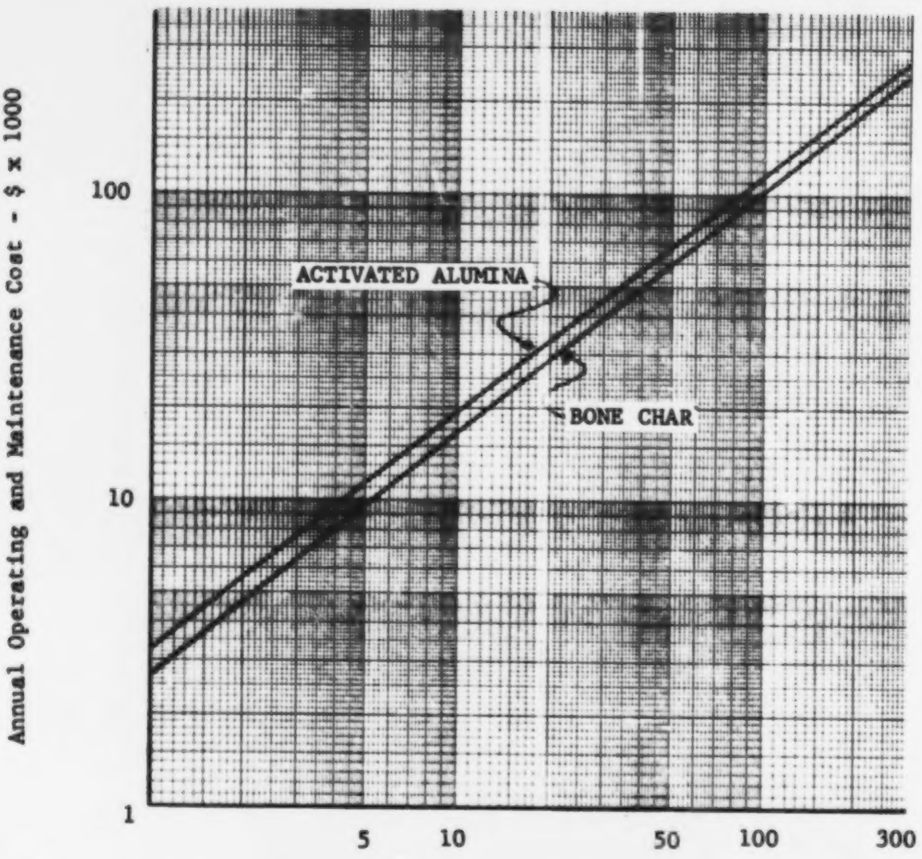

Plant Capacity - m^3/day x 1000

Source - Environmental Planning and Engineering Division

Figure MT-6 - Annual Operating and Maintenance Cost

c. Stabilization and pH Control

The ability of water to scale or corrode is well known, and precautions must be taken to ensure a stable water in a supply system. Almost always this is accomplished by the use of stabilizing or sequestering agents or by pH adjustment, or both.

Using the theoretical treated water quality expected, the stability of the treated water can be predicted. Several procedures and indices to accomplish this have been proposed*, all of them purporting to predict and measure the tendency of water to deposit or dissolve calcium carbonate scale. These indices are related to and derived from the following four mass law equations and one stoichiometric equation.

$$K_s = (Ca^{++}) \times (CO_3^{=}) \qquad (1)$$

$$K_1 = \frac{(H^+) \times (HCO_3^-)}{(H_2CO_3)} \qquad (2)$$

$$K_2 = \frac{(H^+) \times (CO_3^{=})}{(HCO_3^-)} \qquad (3)$$

$$K_w = (H^+) \times (OH^-) \qquad (4)$$

$$\text{Alkalinity} + (H^+) = 2(CO_3^{=}) + (HCO_3^-) + (OH^-) \qquad (5)$$

where:

K_s = solubility product of calcium carbonate

K_1 = first ionization constant for carbonic acid

K_2 = second ionization constant for carbonic acid

K_w = ionization constant for water

( )= concentration in moles/liter of constituent indicated in brackets.

Subsequent investigations have indicated that these equations, and thus the indices, are inaccurate, often to a considerable degree. This is because the water is far from ideal chemically and mathematically, as would be the case if the water was at constant temperature, pH, and contained only calcium carbonate. Each of the ionization constants and the solubility products vary with temperature. The electrostatic interactions of the ions interfere with any one reaction. Electrons in the calcium ions not only react with the carbonate ion electrons, but also bicarbonate, sulfate and other electrons to some degree. This interference effects reaction kinetics and is called the primary kinetic salt effect. In addition, there is a secondary salt effect. In water, salts, even if they do not possess common ions, may change the H^+ or OH^- ion concentration. Consequently, if the reaction is catalyzed by H^+ or OH^-, as Equations (2) through (5) are, the reaction rate will be affected.

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*Langelier Saturation Index; Ryznar Stability Index; Momentary Excess; Driving Force Index; Enslow Stability Indicator.

The most commonly used method of predicting scaling or corrosion tendencies of water is the Langelier Saturation Index.

The formula is:

$$(H^+) = \frac{K_2}{K_s} (HCO_3^-) \quad (Ca^{++})$$

This can be rewritten as:

$$pH = pK_2 - pK_s - \log (HCO_3^-) - \log (Ca^{++}).$$

$$\text{where } pK_2 = -\log K_2$$

$$\text{and } pK_s = -\log K_s$$

If the values of (Ca^{++}), (HCO_3^-), the ionic strength, and the pH are known for a given water, a value of pH called the saturation pH (pH_s) can be computed.

if $pH > pH_s$, the water is scale forming,

if $pH < pH_s$, the water is acidic.

The difference ($pH-pH_s$) is called the Langelier Index, and can be either positive or negative.

The calculation of this index, and thus the prediction of the water characteristics, is complex. Because of this, the American Water Works Association has developed a simple test to assist the plant operator. This test is a rapid method of determining if a water is in balance with solid calcium carbonate. Procedures are given in detail in the AWWA publication "Simplified Procedures for Water Examination".

Table MT-5 shows some of the most commonly used chemicals for stabilization and pH control, and their representative prices. These chemicals are generally introduced into the water as dilute solutions, requiring the use of storage and dilution tanks and metering pumps for handling.

Table MT-5 - Stabilization and pH Control

Chemical name and formula	Common or trade name	Shipping containers	Suitable handling materials	Available forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial strength	Characteristics
Disodium phosphate, $Na_2HPO_4 \cdot 12H_2O$	Basic sodium phosphate, DSP, secondary sodium phosphate	125-lb kegs, 200-lb bags, 325-lb bbls.	Cast iron, steel	Crystal	60-64	0.4 (32 °F), 6.4 (86 °F)	19.8% P_2O_5	Precipitates Ca, Mg, pH of 1% solution, 9.1
Sodium hexametaphosphate, $(NaPO_3)_6$	"Calgon," glassy phosphate, vitreous phosphate	100-lb bags	Hard rubber, plastics, stainless steel	Crystal, flake, powder	47	1–4.2	66% P_2O_5 (unadjusted)	pH of 0.25% solution, 6.0-8.3
Sodium hydroxide, NaOH	Caustic soda, soda, lye	100-, 700-lb drums, bulk (trucks, tank cars)	Cast iron, rubber, steel	Flake Lump Liquid		2.4 (32 °), 4.4 (68 °F), 4.8 (104 °F)	98.9% NaOH, 74-76% Na_2O	Solid, hygroscopic, pH of 1% solution, 13.0
Sulfuric acid, H_2SO_4	Oil of vitriol, vitriol	Bottles, carboys, drums, trucks, tank cars	Concentrated – iron, steel, dilute – glass, lead, porcelain, rubber	Solution (60–66 °Bé)		Complete	77.7% H_2SO_4 (60 °Be); 93.2% H_2SO_4 (66 °Be)	Approx. pH of 0.5% solution, 1.2
Tetrasodium pyrophosphate, $Na_4P_2O_7 \cdot 10H_2O$	Alkaline sodium pyrophosphate, TSPP	125-lb kegs, 200-lb bags, 300-lb bbls.	Cast iron, steel	White powder	68	0.8 (80 °F), 3.5 (212 °F)	53% P_2O_5	pH of 1% solution, 10.8
Trisodium phosphate, $Na_3PO_4 \cdot 12H_2O$	Normal sodium phosphate, tertiary sodium phosphate, TSP	125-lb kegs, 200-lb bags, 325-lb bbls.	Cast iron, steel	Crystal Coarse Medium Standard	 58 58 61	0.1 (32 °F), 13.0 (158 °F)	19% P_2O_5	pH of 1% solution, 11.9

Disodium Phosphate:	35¢/kg
Sodium Hexametaphosphate:	30¢/kg
Sodium Hydroxide:	16¢/kg
Sulfuric Acid:	3¢/kg
Tetrasodium Pyrophosphate:	23¢/kg
Trisodium Phosphate:	33¢/kg

d. Coagulants and Coagulant Aids

Coagulants most commonly used in the United States have been briefly discussed previously in Section IV. Figure MT-7 is a schematic of a typical alum solution system.

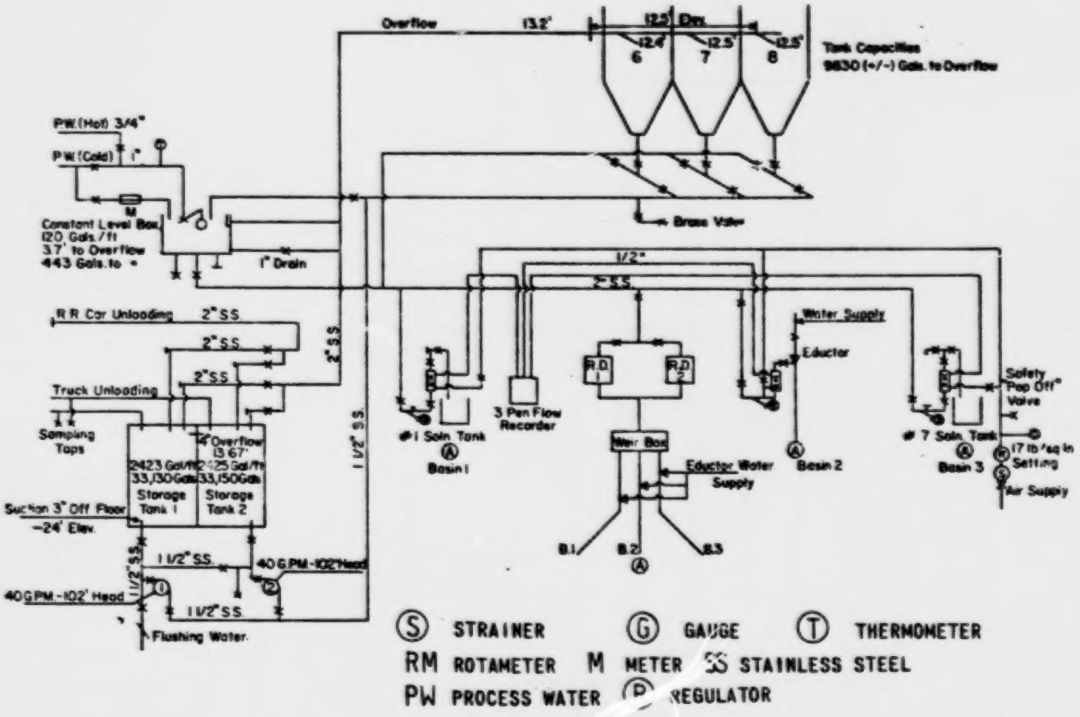
Overflow
13.2'
12.5' Dia.
12.4'
12.5'
12.5'
6
7
8
Tank Capacities
9830 (+/-) Gals. to Overflow
P.W. (Hot) 3/4"
P.W. (Cold) 1"
M
Constant Level Box
120 Gals./ft
3.7' to Overflow
443 Gals. to •
1" Drain
Brass Valve
1/2"
2" S.S.
R.R. Car Unloading
2" S.S.
2" S.S.
2" S.S.
2" S.S.
Truck Unloading
Sampling Taps
4" Overflow
13.67'
2423 Gal/ft
33,130 Gals
Storage Tank 1
2425 Gal/ft
33,150 Gals
Storage Tank 2
Suction 3" Off Floor
-24' Elev.
1 1/2" S.S.
1 1/2" S.S.
1 1/2" S.S.
1 1/2" S.S.
1 1/2" S.S.
40 GPM - 102' Head
40 GPM - 102' Head
1
2
Flushing Water
#1 Soln. Tank
Ⓐ
Basin 1
3 Pen Flow Recorder
R.D. 1
R.D. 2
Weir Box
Eductor Water Supply
B.1
B.2
B.3
Ⓐ
Water Supply
Eductor
Ⓐ
Basin 2
#7 Soln. Tank
Ⓐ
Basin 3
Safety "Pop Off" Valve
17 lb/sq in Setting
Air Supply
Ⓢ STRAINER
Ⓖ GAUGE
Ⓣ THERMOMETER
RM ROTAMETER
M METER
SS STAINLESS STEEL
PW PROCESS WATER
Ⓡ REGULATOR

Figure MT-7 - Typical Alum Solution System

Average costs, and physical and chemical properties for common coagulants are shown in Table MT-6.

The coagulation process is sometimes made more efficient by use of a coagulant aid. The properties and cost of one of these, bentonite, a natural clay, are shown in Table MT-6.

The need for coagulant aids may arise as the result of several factors. The floc formed may be fragile and tend to break up under hydraulic force, it may be light and slow-settling or organic constituents may interfere with the mechanism of coagulation.

Table MT-6 - Common Coagulants

Chemical name and formula	Common or trade name	Shipping containers	Suitable handling materials	Available forms	Weight, lb/cu ft	Solubility, lb/gal	Commercial strength	Characteristics
Aluminum sulfate, $Al_2(SO_4)_3 \cdot 14H_2O$	Alum, filter alum, sulfate of alumina	100-, 200-lb bags; 300-, 400-lb bbls; bulk (carloads)	Dry: iron, steel; solution: lead-lined rubber, silicon, asphalt, 316 stainless steel	Ivory colored: Powder Granule Lump	38-45 60-63 62-67	4.2 (60 °F)	15-22% Al_2O_3	pH of 1% solution, 3.4
Ammonium aluminum sulfate, $Al_2(SO_4)_3(NH_4)_2SO_4 \cdot 24H_2O$	Ammonia alum, crystal alum	Bags, bbls, bulk	Duriron, lead, rubber, silicon, iron, stoneware	Lump Nut Pea Powdered	64-68 62 60 60	0.3 (32 °F), 8.3 (212 °F)	11% Al_2O_3	pH of 1% solution, 3.5
Bentonite	Colloidal clay, volclay, wilkinite	100-lb bags, bulk	Iron, steel	Powder, pellet, mixed sizes	60	Insoluble (colloidal sol used)		
Ferric chloride (a) $FeCl_3$ (35-45% solution)	Ferrichlor, chloride of iron	5-, 13-gal car boys, trucks, tank cars	Glass, rubber, stoneware, synthetic resins	Dark brown syrupy liquid		Complete	37-47% $FeCl_3$ 20-21% Fe	
(b) $FeCl_3 \cdot 6H_2O$	Crystal ferric chloride	300-lb bbls		Yellow-brown lump			59-61% $FeCl_3$ 20-21% Fe	Hygroscopic (store lumps and powder in tight containers), no dry feed; optimum pH, 4.0-11.0
(c) $FeCl_3$	Anhydrous ferric chloride	500-lb casks, 100-, 300-, 400-lb kegs		Green-black powder			98% $FeCl_3$ 34% Fe	
Ferric sulfate, $Fe_2(SO_4)_3 \cdot 9H_2O$	"Ferrifloc," Ferrisul	100-, 175-lb bags, 400-, 425-lb drums	Ceramics, lead, plastic, rubber, 18-8 stainless steel	Red-brown powder 70 or granule 72		Soluble in 2-4 parts cold water	90-94% $Fe_2(SO_4)_3$ 25-26% Fe	Mildly hygroscopic, coagulant at pH 3.5-11.0
Ferrous sulfate, $FeSO_4 \cdot 7H_2O$	Copperas, green vitriol	Bags, bbls, bulk	Asphalt, concrete, lead, tin, wood	Green crystal granule, lump	63-66	0.5 (32 °F), 1.0 (68 °F), 1.4 (86 °F)	55% $FeSO_4$ 20% Fe	Hygroscopic; cakes in storage; optimum pH 8.5-11.0
Potassium aluminum sulfate, $K_2SO_4Al_2(SO_4)_3 \cdot 24H_2O$	Potash alum	Bags, lead-lined, bulk (carloads)	Lead, lead-lined, rubber, stoneware	Lump Granule Powder	62-67 60-65 60	3.0 (68 °F), 3.3 (86 °F)	10-11% Al_2O_3	Low, even solubility, pH of 1% solution, 3.5
Sodium aluminate, $Na_2OAl_2O_3$	Soda alum	100-, 150-lb bags, 250-, 440-lb drums, solution	Iron, plastics, rubber, steel	Brown powder, liquid (27 °Be)	50-60	Complete	70-80% $Na_2Al_2O_4$ min 32% $Na_2Al_2O_4$	Hopper agitation required for dry feed
Sodium silicate, Na_2OSiO_2	Water glass	Drums, bulk (tank trucks, tank cars)	Cast iron, rubber, steel	Opaque, viscous liquid			38-42 °Be	Variable ratio of Na_2O to SiO_2, pH of 1% solution, 12.3

Aluminum Sulfate : 13¢/kg
Ammonium Aluminum Sulfate : 19¢/kg
Bentonite : 30¢ to 45¢/kg
Ferric chloride : 30¢/kg

Ferric Sulfate : 4¢/kg
Ferrous Sulfate : 6¢/kg
Potassium Aluminum Sulfate : 20¢/kg
Sodium Aluminate : 26¢/kg
Sodium Silicate : 6¢/kg

This latter problem can be most easily resolved by "breakpoint" chlorination prior to coagulation. The chlorine demand is satisfied, and excess chlorine is added to oxidize the organic materials. Needless to say, this technique can be very costly, and does not negate the requirement for post chlorination.

Bentonite is the common weighting agent in use as a coagulant aid. It is a naturally occurring clay which is generally used at a rate of 10 - 50 mg/l.

Activated silica is used extensively as a coagulant aid, its advantages being threefold. It provides a tough shear-resistant floc, it increases the density of the floc, and increases the rate of coagulation, under suitable conditions. It also tends to reduce the dose of coagulant required, and improve the color removal capabilities of the system. An application rate of 7 to 11 percent of the coagulant dose is current practice.

Considerable care must be exercised to ensure precise control of the production of the active solution. Automatic equipment is available which will produce a continuous supply of activated silica at the point of use. Improper control of the solution production might induce extremely large flocs that result in high residual turbidity, and rapid clogging of the filtration surface.

Polyelectrolytes have recently found wide application as coagulant aids. These synthetic organic materials consist of small molecules chemically bound to form a polymer of colloidal size. Their greatest asset is the remarkable increase in floc size generated by the addition of small amounts of these materials. It is generally unnecessary to add more than 1 mg/l, and this produces an increase in floc size of several orders of magnitude. While these materials are fairly expensive, the small dose requirement coupled with the rapid increase in floc settlement, and the resultant savings in operating costs makes their use economically attractive in many cases.

Table MT-7 - Some Typical Polyelectrolytes and their Maximum Health Concentration Recommended by the Environmental Protection Agency

Produce	Maximum Concentration Recommended mg/1	Cost $/kg (Oct. 1973)
Percol LT-20	1	.52
Superfloc 127	1	.43
Magnifloc 521-C	10	.09
SORBO	20	.08
Poly-Floc 4D	25	.09
Burtonite No. 78	5	.23
Drewfloc No. 3	3	.22
Hercofloc 818	1	.49
Zeta-Floc C	20	.03
O'B Floc	10	.15

e. Softening

Softening for municipal purposes generally is accomplished using the cold lime or lime-soda process. Ion exchange is also used, using zeolite in the sodium form as the exchange medium.

The addition of hydrated lime produces the following reaction with bicarbonate hardness:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightleftharpoons 2CaCO_3\downarrow + 2H_2O$$

$$Mg(HCO_3)2 + 2Ca(OH)_2 \rightleftharpoons Mg(OH)_2\downarrow + 2CaCO_3\downarrow + 2H_2O$$

The soluble bicarbonate hardness is thus converted into insoluble carbonate and hydroxide hardness, which comes out of solution, and is removed by sedimentation and filtration. In lime softening, there is also reduction of the total dissolved solids content of the raw water.

Hydrated lime also reacts with the permanent or noncarbonate magnesium hardness thus:

$$MgSO_4 + Ca(OH)_2 \rightleftharpoons Mg(OH)_2\downarrow + CaSO_4$$

The magnesium hydroxide precipitate is a gelatinous form which serves as a coagulant. In some cases, however, coagulant aids are added in small amounts to assist sedimentation of the precipitates.

$$MgCl_2 + Ca(OH)_2 \rightleftharpoons Mg(OH)_2\downarrow + CaCl_2$$

As a result of these reactions, permanent magnesium hardness is removed, but the soluble salts, calcium sulfate and chloride are introduced, thus increasing the residual calcium permanent hardness. In order to overcome this problem, soda ash is added in conjunction with lime thus:

$$CaSO_4 + Na_2CO_3 \rightleftharpoons CaCO_3\downarrow + Na_2SO_4$$

$$CaCl_2 + Na_2CO_3 \rightleftharpoons CaCO_3\downarrow + 2NaCl$$

The sum of these is lime-soda softening. Although these reactions remove the permanent calcium hardness which would result from lime treatment only, there is no decrease in total solids, due to the introduction of soluble sodium salts.

If the raw water is highly alkaline, the concentration of sodium bicarbonate is generally responsible. Water of this type has a total alkalinity greater than total hardness, and by softening with lime only, the soda ash treatment becomes an integral part of the process, according to the equations:

$$2NaHCO_3 + Ca(OH)_2 \rightleftarrows Na_2CO_3\downarrow + CaCO_3 + 2H_2O$$

$$CaSO_4 + Na_2CO_3 \rightleftarrows CaCO_3\downarrow + Na_2SO_4$$

In ion exchange, the calcium and magnesium ions in the water are almost totally replaced by sodium. According to the equation:

$$\underset{\text{Sodium Zeolite}}{2(Z\text{-}Na)} + Ca^{++} \rightleftarrows \begin{matrix}Z\\Z\end{matrix}>Ca + 2Na^{+}$$

Upon exhaustion, the zeolite is regenerated with NaCl solution.

The efficiency of the lime-soda ash process is based upon four essential factors:

- proper selection of specific reagents to efficiently precipitate part of the impurities to be removed in the form of an insoluble sludge and to convert the remainder to a soluble (and innocuous) form
- correct proportioning of the specific chemical reagents to the raw water
- propagating the chemical precipitating reactions by a suitable combination of coagulation, sedimentation, heat or sludge contact
- filtration of the chemically softened or finished water to remove traces of turbidity resulting from the process

Table MT-8 illustrates the chemical balances obtained in softening the same water with different objectives. The second column in this table shows the softener effluent balances when lime is used to remove only calcium and not the magnesium. Of course, only carbonate calcium hardness is removed but this is achieved at minimal chemical cost. In the third column one finds still further reduction in calcium but use of soda ash was necessary to further force calcium precipitation.

Complete lime-soda softening, including reduction in magnesium, is shown by the fourth column. To achieve this, it was necessary to increase considerably the dosage of lime and soda ash, resulting in higher effluent water alkalinity. The table illustrates effectively the large growth in lime and soda ash demand for a small reduction in total hardness.

Table WT-8 - Lime/Lime Soda Softening Balances *

	Raw Water	Lime Softening for Calcium Removal	Selective Calcium Softening with Lime and Soda Ash	Lime-Soda-Ash Softening
Total Hardness as $CaCO_3$	160	80	69	52
Calcium as $CaCO_3$	110	35	24	24
Magnesium as $CaCO_3$	50	45	45	28
"P" Alkalinity as $CaCO_3$	0	17	22	60
"M" Alkalinity as $CaCO_3$	130	50	60	82
Sulfate as SO_4	48	48	48	48
Chloride as Cl	16	16	16	16
		Chemical Treatment Requirements		
Lime		98	98	156
Soda Ash			22	64

* all figures in terms of mg/l

Softening is often carried out at the same time as coagulation and sedimentation, either in basins or in solids-contact type equipment. Thus the capital costs are essentially the same as these two operations. The additional cost of softening will be the cost of lime and soda-ash, and the feeding equipment. Since the cost of the feeding equipment is relatively low, it may be excluded from a planning level estimate.

The amount of lime and soda-ash required may be computed from the factors given in Table MT-9

Table MT-9 - Factors used to Calculate
Lime and Soda Ash Requirements kg /1000m^3

From Raw Water Analysis (mg/l as $CaCO_3$)	Requirements	
	Lime* CaO (90%)	Soda Ash* Na_2CO_3 (98%)
CO_2	x 1.42	-
Total Alkalinity	x .623	-
Required Magnesium Reduction	x .623	1.081
Ca Noncarbonate Hardness	-	1.081

*or better.

Lime cost can be assumed to be : 2 cents/kg
Soda ash cost can be assumed to be : 8.5 cents/kg

The changes in water analysis brought about by the addition of softening and other water-conditioning chemicals can be computed by using the data contained in Table MT-10.

Table MT-10

Changes in Water Analysis (in mg/l) Caused by the Addition of

One mg/l Coagulants, Chlorine, Hydrated Lime, or Sulfuric Acid

Chemical	Formula	Reduced Alkalinity as $CaCO_3$	Increased Alkalinity as $CaCO_3$	Reduction in CO_2 as CO_2	Increase in CO_2 as CO_2	Increase in SO_4 as $CaCO_3$	Increase in Cl as $CaCO_3$	Increase in $CaCO_3$
Aluminum sulfate(filter alum)	$Al_2(SO_4)_3 14H_2O$	0.45			0.40	0.45		
Ferrous sulfate (copperas)	$FeSO_4 7H_2O$	0.36			0.31	0.36		
Ferric sulfate (ferrisul)	$Fe_2(SO_4)_3 2H_2O$	0.75			0.66	0.75		
Chlorine	Cl	1.40			0.30		1.4	
Hydrated lime (93% pure)	$Ca(OH)_2$		1.26	1.11				1.26
Sulfuric acid (93% pure)	H_2SO_4	0.95			0.84	0.95		

Softening by ion exchange is a very simple operation, much used in home softening units. The economics of using the process on a municipal scale depends primarily on whether or not softening is to be the only treatment, or if coagulation and sedimentation is to be used also. If so, it is undoubtedly cheaper to use lime or lime-soda with the coagulants.

Zeolite softening costs can be estimated using the following:

Capital Cost - \$5500 per 100mg/l $CaCO_3$ hardness removed per 1000 cubic meters of water softened per day.

Annual Operating Cost - \$1000 per 100mg/l $CaCO_3$ hardness removed per 1000 cubic meters of water softened per day.

For example, suppose it is necessary to remove 180mg/l $CaCO_3$ hardness in a 6000m^3/day plant.

Capital cost = \$5500 x 1.80 x 6 = \$59,400

Operating cost = \$1000 x 1.8 x 6 = \$10,800/year.

f. Dechlorination

It is sometimes necessary or desirable to reduce the residual chlorine in a water supply for aesthetic reasons. Several techniques can be employed for this purpose, among the most feasible technically and economically being activated carbon absorption, aeration, and the use of sulfur dioxide and related compounds.

The use of sulfur dioxide or its derivatives is rapid and insures good results. It is a practice widely used in water treatment, sulfur dioxide being first used in North America by Howard in Toronto in 1926. Sodium bisulfite and sodium sulfite are also used, the former being cheaper and more stable. The equations describing the dechlorination are:

$$SO_2 + Cl_2 + 2H_2O \longrightarrow 2HCl + SO_3$$

$$Na\ HSO_3 + Cl_2 + H_2O \longrightarrow Na\ HSO_4 + 2HCl$$

bisulfite bisulfate

$$Na_2\ SO_3 + Cl_2 + H_2O \longrightarrow Na_2SO_4 + 2HCl$$

bisulfite sulfate

As can be seen, the products of the reaction are acidic, and thus tend to decrease the alkalinity of the dechlorinated water.

The doses required for each "dechlor" are:

Sulfur dioxide - 0.90 mg/l per mg/l Cl_2 removed

Sodium bisulfite - 1.46 mg/l per mg/l Cl_2 removed

Sodium sulfite - 1.77 mg/l per mg/l Cl_2 removed

Approximate costs are:

Sulfur dioxide - 25¢/kg

Sodium bisulfite - 16¢/kg

Sodium sulfite - 24¢/kg

Activated carbon and aeration can also be employed for dechlorination. These techniques and costs have been discussed previously in this section.

SECTION V

TREATED WATER STORAGE

General

Treated water reservoirs are used in waterworks to perform the function of service storage. The three major components of service storage are: (1) equalizing, or operating, storage; (2) fire reserve; and (3) emergency reserve.

1. Equalizing, or operating, storage

Because of the varying rate of demand for water during the day, many cities find it necessary to provide reservoirs that permit water treatment or pumping plants to operate at a reasonably uniform rate and provide water from storage when the demand exceeds this rate.

2. Fire reserve

Based upon the durations of serious conflagrations that have been experienced in the past, the recommendations of the National Board of Fire Underwriters are that distribution reservoirs be made large enough to supply water for fighting a serious conflagration for 10 hours in communities of 6000 people or more, and for 4-8 hours for smaller ones.

3. Emergency reserve

The magnitude of this component of storage depends on (1) the danger of interruption of reservoir inflow by failure of supply works; and (2) on the time needed to make repairs. The emergency reserve is sometimes taken as equal to 25% of total average capacity. The National Board of Fire Underwriters bases its rating system on an emergency storage of five days at maximum flow.

Classification

Where topography and geology permit, the water stored for distribution is held in reservoirs that are formed by impoundage, by balanced excavation and embankment or by masonry construction.

a. Open and covered service reservoirs

Treated water storage reservoirs should be covered at all times in order to protect the water against chance contamination and deterioration. The covering of open finished water reservoirs is not a requirement of the Environmental Protection Agency. However, the practice is recommended and endorsed by the Agency and is required by some states. In the event it is impossible to cover a reservoir, there are certain safeguards that must be observed: (1) the reservoir should always be fenced (2) Where the reservoir is so placed that runoff can be carried into it - a margin intercepting drain should be provided for its protection from such runoff. Other methods of safeguarding open reservoirs will be dealt with further.

i. Contamination of Open and Closed Service Reservoirs

Treated water storage facilities can never be completely sealed and as a result are susceptible to contamination.

Inferior reservoir construction can allow serious contamination in any type of reservoir. Pollutants may enter the reservoir through leaky roofing, with rainwater, and in the case of subsurface storage, faulty sealing. Poorly designed or installed ventilation systems may allow the entrance of windblown contaminants as well as birds, insects, rodents and other small animals capable of contaminating the stored water. Poorly constructed reservoir roofs can be worse than no roof, as far as contribution of degrading materials is concerned. Covered and uncovered reservoirs located in windy and dusty areas can be subject to windblown dusts that enter through vents. This dust can contribute significant numbers of coliform organisms to water in the reservoir.

The open service reservoir is particularly susceptible to airborne pollutants such as bacteria, agricultural chemicals, etc. These contaminants may enter the reservoir directly through wind or rain action. Open service reservoirs are also subject to various types of algal growth which in turn impart undesirable tastes, odors and color to the water. Sedimentation can be a major problem in large open reservoirs, requiring frequent draining and cleaning, to prevent the development of weed growth. The AWWA report on the Committee on Open-Air Reservoirs gave evidence on widespread organic pollution in open reservoirs by gulls, ducks and other birds; animals and rodents, such as mice and rats, dogs, cats and frogs. Humans were found to contribute significantly to contamination through bathing, fishing, and other water-related activities.

Night swimming in large or isolated reservoirs is extremely hard to prevent even when fences and watchmen are provided. Wires strung across open reservoirs intended to keep ducks and gulls away provide perches for swallows, starlings and other small birds. This situation is a potential danger as bird droppings have been linked to disease transmission.

The prudence of using open service reservoirs has been questioned by the 1929-1930 APHA Committee on Water Supply. The committee made the following comment:

> "The committee would urge that more study be given open reservoirs throughout the country by the various water departments with the hope of reducing the number to a minimum. Enough information is now available to throw doubt on the wisdom of using open reservoirs without continuously chlorinating the water. B. coli growing on microorganisms does not constitute a menace to health,(SIC)

but if we become accustomed to assuming that bacterial increases in the distribution system are natural growths and of no significance the occasional occurrences of real pollution will also be ignored."[1]

ii. Prevention of Contaminants in Open and Closed Reservoirs

Open potable-water storage reservoirs should be fenced. Experience has shown that even a 2.8 m fence topped with barbed wire will not keep out those determined to enter a reservoir. Too much dependence on a manproof fence is therefore futile. Fencing should be of such material and construction to prevent the passage of children and such animals as dogs, cats and rabbits and will discourage the less determined youths from pranks. The fence should be located a sufficient distance from the water to eliminate the pleasure found in watching objects thrown in the water. Access gates should be kept locked. Indirect pollution in open reservoirs can be mitigated by providing flow-through circulation and by treating the influent and stored water. However, despite such measures, unsatisfactory conditions have not infrequently developed in open reservoirs.

Obviously, properly designed and constructed covers would eliminate the cause of direct pollution previously noted. Covers on reservoirs must be structurally sound in order to withstand wind pressure, snow and ice, earthquake strains and the like. The materials should be and continue light-tight and impervious to dust and polluting agents. Plywood panels on steel rafters can be satisfactory if properly designed and if sufficient maintenance is received. Standard concrete, lightweight concrete dome and steel construction are among the more usual and more permanent covers. The "standard" concrete cover designs are generally practical if the reservoir is to be buried under earth. For those not to be buried, the lightweight concrete dome and steel covers are more practical. The economics involved in covering reservoirs could be an overwhelming problem. Low cost floating covers such as butyl rubber and nylon-vinyl membrane have been tried successfully. However, in using floating covers, care must be taken to insure the proper handling of any problems which might endanger the integrity of the cover such as rainwater and ice formation. The City of Charleston, S.C. installed strong permanent leakproof covers of synthetic rubber on two cement reservoirs. The covers not only protected the water from airborne pollutants and debris, but also prevented chemicals (e.g. chlorine) and the water itself from evaporating. Reservoirs below the ground surface should be located at elevations above groundwater levels to avoid infiltration and possible flooding or inundation from surface stream or storm water.

At any rate the reservoir must be sealed to prevent infiltration when empty. Protective coatings (FDA or EPA approved), preservatives and joint sealers should be used or applied in a manner which will not contaminate the stored water. The coatings, if used, on the inside of a reservoir must resist abrasion from ice formation, have good adhesion, and the ability to withstand alternate wetting and drying in addition to constant immersion without flaking. Many types of rubber and plastic sheet lining material and liquid sealants are available for a wide range of applications. Butyl rubber used for covers can also be used for linings. Gunite, a sand-cement-water mixture, discharged from a nozzle or gun through and onto a mat of reinforcing steel, has been employed to line or reline the invert and sides of reservoirs. An asphalt-plastic liner is available on the market for use in the storage and containment of potable water. The manufacturer claims that the liner does not impart taste or discoloration to potable water.

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[1] Committe report: Bacterial Aftergrowths in Water Distribution Systems, Am. J. Public Health, 43:485 (1930).

Some very salient protection features for reservoir protection are as follows:

1. The cover of the reservoir and the ground surface about the reservoir should be graded in such a manner as to divert surface water and prevent pooling within the vicinity of the reservoir.

2. The discharge end of all overflow, blowout or cleanout pipes should be turned downward and screened to prevent the entrance of rain, dust, birds, insects, rodents and other contaminating materials. They should also be able to discharge freely, without any chance of backflow of contaminated water or material. If the discharge is to a control chamber located where the overflow will be above ground and flood level, it may be drained by gravity directly to the ground surface or indirectly into a storm drain; otherwise it should be drained by pumping.

3. Whenever practical, a suitable and substantial cover should be provided for any reservoir, elevated tank or the structure used for water storage. Covers should be generally of lightweight, watertight, durable material and construction, and designed to facilitate drainage from the cover and prevent contaminating materials from getting into the stored water.

4. Manholes on reservoir covers should be fitted with raised watertight walls projecting at least 15.24 cm above the level of the reservoir cover or any fill material placed over the cover. Manhole covers should be solid and watertight, preferably with edges projecting downward at least 5.08 cm around the outside of the frame. Each manhole cover should be locked securely with a sturdy lock.

5. Vents and openings, where necessary on covers of reservoirs for water level control guages or other purposes, should be constructed and screened to prevent the entrance of dust, rain, snow, birds, insects or other foreign matter.

6. The operation of storage reservoirs should be conducted in such a manner as to maintain the highest sanitary quality of water.

iii. Removal of Contaminants in Reservoirs

Free or combined chlorine residual may be maintained if the reservoir is of the flow-through type and the size is not too large in relation to the flow. In open reservoirs, free residual chlorine, chloramine, copper sulfate and activated carbon were suggested for control of microscopic growth. Disinfection facilities should be set up so all the water reentering the distribution system will be re-treated.

b. Elevated Storage Tanks

Elevated storage in many cases has proven to be the most practical and economical method for providing adequate storage and pressure in the distribution system. Where natural elevation is inadequate to provide the proper pressure, standpipes and elevated tanks are the two most suitable types of water storage. The construction can be of wood, concrete or steel. In cold climates steel is found to be the most practical. In reinforced concrete, unless the steel is prestressed, vertical cracks are formed, and leakage and freezing cause rapid deterioration of the structure. Wood type storage tanks are almost wholly confined to railroad and industrial supplies. The water tower is often a community's tallest structure and stands out prominently. As a result, there has been concern with the aesthetics in water towers, which in turn has produced a myriad of shapes and sizes of storage tanks and standpipes.

The major problems with storage tanks and standpipes are contamination by corrosion and leakage. These two factors are mainly a matter of design considerations dictated by the economics of the situation. Steel is competititve in cost to concrete and is more watertight but involves more periodic maintenance to alleviate corrosion. Concrete on the other hand, is much less susceptible to corrosion but is more prone to leakage. As in the case of reservoir design, a wide range of rubber and plastic sheet lining material and liquid sealants are available to aid the prevention of contamination and leakage in elevated tanks and standpipes. Improved paint systems now available, and increased use of cathodic protection systems have reduced the chances of contamination by corrosion products from steel tanks in addition to increasing the life expectancy of the tanks. Guidance for preparing and painting storage tanks is provided by AWWA Specifications D102 Coatings and Cathodic Protection. Paint coatings are applied to submerged steel surface areas for the sole purpose of isolating the steel from the corroding medium. All coatings are subject to deterioration in service due to water absorption, abrasion, bond failure, delamination, and ice damage. There are literally scores of variables that have a direct effect on the rate of corrosion activity within a structure.

Cathodic protection offers a viable resistance to corrosion. However, cathodic protection requirements change from time to time and from place to place. For any given utility structure, the amount of cathodic protection currently required to achieve and maintain a protection condition changes scores of times each day. Given two identical storage structures with identical coatings and storing identical waters, different degrees of cathodic protection needs will exist. The coating industry has recognized the need for more sophisticated coating systems and have improved their products and application techniques. The cathodic protection industry has also recognized its responsibility to keep pace so that its installed systems do their job of corrosion control more economically and efficiently.

A less perplexing but nonetheless existing problem is the problem of foreign materials entering storage tanks by way of vents. As in the case of reservoirs, all vents should be screened and protected so that roof drainage cannot be deflected through openings. Protection should be provided particularly in landscaped areas where fertilizers might be used. Algal spores may also enter through the vents and stimulate the growth of algae. Customer complaints can be an indication as to the presence of contamination in the storage system. However, complete water sampling and analysis, and an intelligent review of water quality data must be accomplished to properly evaluate the degree of contamination. Disinfection and periodic cleaning will alleviate these problems. Adequate disinfection of storage tanks after construction or repairs is necessary to prevent degradation in the distribution system water quality. Spraying strong solutions of chlorine on the surface of the storage tanks after thorough initial flushing, followed by filling with chlorinated water has proved satisfactory.

Cost Data

a. Reservoir Corrosion Protection

Reservoir liners
  asphalt-plastic liners
    material and labor - $0.6 - $0.12 per sq m
    (includes gussetting and excludes site preparation)

  butyl rubber lining
    material costs $0.6 per sq m

  gunite sealing

Reservoir covers
  butyl rubber floating covers
    material $0.09 per sq m

  steel covers *

  concrete covers *

Water towers and storage tanks protection
  cathodic protection for corrosion control

installation costs

600 - cu meters storage tank	$2,000.00
2,000 - cu meters storage tank	$2,700.00
4,000 - cu meters storage tank	$3,330.00

(The preceeding costs are for manual cathodic systems only. For automatic systems, each cost is increased $800.00)

coatings for corrosion control

Labor to apply coatings vary with coating product. Average labor costs are:

Blasting and applying 1 coat 5¢ per sq m
add 0.5¢ for each additional coat for 1-5 coats

b. Distribution Systems Protection

Corrosion Control

installation costs for population of 1.5 million are:

uncoated pipe	$200,000
coated pipe	$100,000 - 120,000

*cost for these items are dependent on the design of the reservoir cover.

- coatings
  - bimetallic glassy phosphate
    - material cost $0.01 - $0.15 sq m
  - vinyl resins
    - material cost $0.01 - $0.15 sq m

SECTION VI

CONTROL OF WATER QUALITY IN DISTRIBUTION SYSTEMS

General

Often it is fallaciously assumed that water entering the distribution system from storage will be of the same quality at the consumers tap. The quality of water must be preserved during its conveyance from the point of production and storage to delivery to the consumer. Theoretical conditions for accomplishment of complete control are:

i. The finished water is completely stable in its compositional and physical attributes.

ii. It is completely disinfected.

iii. The conveyance system and accessory structures are relatively inert to the water being conveyed.

iv. The conveyance system is sealed off from contaminating intrusion.

Such conditions are rarely all achieved throughout the operational distribution system, and results in deterioration due to: poor-quality water put into distribution system; chemical interaction between water and pipe; biological degradation; biological infestation; cross connection hazards; inadequate main disinfection; and less common factors such as blowoffs and vacuum or air relief valves improperly constructed or located. The consequence may be one or more of the following; unsafe water, turbid or rusty water; unpleasant taste and odor; or colored water.

Cross Connections

A hydraulic linkage permanently or temporarily connecting an additional source of water with the pipes of a potable water supply is called a cross connection. Unless the quality of the supplementary water supply is equal or superior to that of the potable supply and unless it is so maintained at all times, neither direct nor indirect cross connections should be tolerated. The hazards of cross connections may result from either pumping or "back siphonage".

Pumping hazards are those causing backflow of foreign liquids into the potable water system, resulting from interconnection of the domestic water system to a second system of pipes, tanks, or the like, containing water or other liquids under pressure maintained from some source other than the potable water system. The pressure may be, or can be, higher than the pressure in the potable water system at the point of interconnection.

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These hazards can exist at water service connections to sewage or storm water pumping stations, sewage-treatment plants, waterfront properties, industrial plants handling liquids under pressure, and buildings where sewage is pumped on the premises. Such interconnections may result in large quantities of dangerous materials such as sewage and toxic chemicals entering the potable water system through backflow.

One of the major items in a cross-connection control program is the protection against these pumping hazards in a system. Removal of the basic cause (such as abandonment of a sewage-polluted auxillary source) will provide such protection. Protection can also be obtained by delivering water from the potable water supply overhead - through an "air gap" - to a receiving tank, or by installing a backflow-prevention device at the service connection. The latter two actions mentioned will protect the potable water supply but will not protect the people drinking water within the property under consideration. Depending on the region some health authorities will only accept air-gap separation (or abandonment of polluted supplementary source) as protection against the above stated pumping hazard. Where an air-gap separation is not practical some health authorities will accept a reduced-pressure-principle device. Another backflow prevention device; a double check valve assembly, can provide acceptable protection against backflow from nontoxic materials in industrial premises handling such nontoxic materials under pressure, for example the carbonated beverage industry. Cross connections permitting backflow of nontoxic materials into the potable water supply may not create public health hazards, but can create objectionable conditions.

Back siphonage is another means of contaminating a potable water supply. It occurs when negative pressure develops, either in the water users piping system or in the community piping system.

Negative or subatmospheric pressures in a piping system can cause the transfer of polluted or used water or other liquids from a water using fixture into a building piping system and, under extreme conditions, into the potable water system. Back siphonage hazards therefore, presents more of a threat to water consumers within a building than to a potable water system on a whole. As long as adequate pressure is always maintained at the point of service from a potable water system to a customer's piping, back siphonage will not affect the potable water supply. Negative pressure more frequently occurs in building piping systems. It is due to either insufficient internal hydraulic capacity or to low pressure in the potable water system. Negative pressure also occurs in community piping systems and is due to: main breaks; planned shutdowns; fire demands; water usage exceeding the hydraulic capacity of the system; and other reasons. Negative pressure should not be tolerated. A positive pressure is necessary to prevent contaminated infiltration, such as leakage from nearby sewer lines, into the system.

Disinfection of Mains

Water treatment does not usually produce coliform-free water. The control of these organisms is relative and not absolute. Distribution systems are rarely free from coliform organism unless residual chlorine is always present and other adverse conditions do not exist. In waterworks the presence of coliform organisms act as an indicator of pollution and are not usually considered as pathogenic. The existance of these organisms however, should always be considered as presumptive evidence of pollution. Among the sources of bacteria are: cross connections, infiltration due to low or negative pressure, and ineffective or non-existent main disinfection.

Standards for the disinfection of mains have been set down by AWWA (C601-68). The standards describe procedures for protecting the cleanliness of the pipe during laying. It calls for preliminary flushing of new lines and specifies chlorination to produce a residual of at least 25 mg/l after 24 hours of standing in the treated pipeline. Procedures are also described for disinfecting repaired lines. These standards along with the "Standards for Installation of Cast Iron Water Mains" (AWWA C600), approve only rings, asbestos rope or treated paper as yarning or packing material. Other packing materials such as jute and hemp generally contain coliform organisms and are extremely hard to disinfect, consequently they are prohibited. Such contaminated packing may not constitute a public health hazard, but contributes to a continued coliform presence in water flowing in new mains despite all reasonable efforts to disinfect the lines.

Chemical Interaction Between Water and Pipe

Corrosion is an electrochemical process that causes pitting of main pipe, deposition of ferric hydroxide (rust), tuberculation and lime scaling, blue-green stains on enamel bathroom fixtures (from copper and brass pipe and fittings), and sometimes the formation of toxic lead salts in lead pipes. This chemical interaction between water and pipe leads to the deterioration of metal in the community and household piping system, rusty (or red) water, and a reduction in the water carrying capacity of the water mains.

Tuberculation and pitting, the most serious types of corrosion frequently occurs when the pH value of the water is between 7.0 and 10.0. In this pH range the corrosion tends to be localized in nature. The corrosion products are precipitated in place to form tubercles which are pervious to water and therefore promote rather than stifle further attack. The resulting pits may soon penetrate steel pipe, making replacement necessary. Even before the pipe fails, the tubercles formed can seriously impede the flow of water. Lime scaling also impedes the flow of water and is especially serious whenever a water high in bicarbonate hardness is heated or an unstable water is discharged from a lime or lime soda softener. This is particularly true in industrial heat exchangers, condensers and hot water systems.

There are numerous methods for combating corrosion and any specific problem can have more than one method of solution. Very often two or more methods are used to supplement one another. The methods of combating corrosion can be classified into six general categories. These are as follows:

i. Alloying or use of better corrosion resistant pipes.

ii. Coatings (organic and inorganic)

iii. Alteration of pipe environment

iv. Non-metallic pipes (Plastic)

v. Cathodic protection

vi. Design.

Almost all of the methods of combating corrosion listed above have been employed. The use of alloying or better corrosion resistant material is employed whenever metals other than steel are used, such as in copper.

The National Bureau of Standards has conducted long-term corrosion tests of underground pipe line materials, including steel, cast iron, and ductile cast iron. A comprehensive analysis of this data was made by the Bureau of Reclamation of the Department of the Interior, the "Pennington Report".[1] It was found that gray cast iron pits 1.8 times as much as steel in a soil where steel will pit at an average depth of 40 mils the first year. In the same type of soil, ductile cast iron will develop maximum pits 2.6 times as deep as those in steel.

In corrosive soils the expected life of 6" Class 22 gray cast iron would be in the order of 26 years, the expected life of ductile cast iron 6" Class 22 would be 9 years and bare steel 0.18 cm thick, 3 years. In 24" size, Class 23 gray cast iron life would be 97 years, Class 1 Ductile, 15 years and 0.33 cm steel, 10 years. Assuming a theoretical pipe 0.64 cm thick of each of these materials, the calculated life would be 35 years for steel, 11 years for gray cast iron and 5-1/2 years for ductile cast iron.

Corrosion rates are not linear with time. The expected life is based on complete penetration of the pipe wall by corrosion. No credit was given to the value of corrosion products remaining intact.

The Pennington Report concluded that all pipe must be protected against corrosion in most instances and that the use of carbon steel properly protected was more economical than using gray cast iron or ductile cast iron.

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[1] Corrosion of Steel and Two Types of Cast Iron Pipe in Soil, W. A. Pennington, Highway Research Record No. 140, 1966, Highway Research Board, pp. 9-22.

Metallic or inorganic coatings would include the use of galvanized pipes and the use of concrete as a coating on steel. Organic coats consist of a wide range of products such as; coal tar, asphalt, wax, plastic tapes, epoxy resins, vinyl resins and paints, and organic zinc paints.

Concrete coated steel is extensively used for pipes 16" and larger. The concrete provides a protective coating for the steel and inhibits corrosion. Cured concrete normally maintains the pH at about 9.5 to 12.5 which can furnish a protective environment for steel. There are situations where concrete coated steel should not be used without further corrosion measures. Furthermore, the concrete must completely cover the pipe or else corrosion will be accelerated on the uncovered portion. The concrete protective film will break down if the cover is too thin or if the cement, concrete or water contains excessive chlorides. In a recent investigation severe corrosion resulted in steel with concrete covers of 2.54 cm or less. The most severe corrosion of steel in concrete was due to the presence of chlorides. In one case 21 km of prestressed pipe failed, most of it before being installed.

Organic type coatings have been commonly used in the past, however, their effect on corrosion has limitations. They tend to concentrate the effects of corrosion since it is difficult to cover 100% of the pipe. It can be calculated that even a 99.9% perfect coating of a 0.15 m pipe will have 0.52 m^2 of base metal per kilometer. Coatings may also deteriorate with age and further expose the metal to corrosion.

The addition of certain chemicals to the water as part of the treatment in order to deposit a protective coating or film on metals is a very widespread, practical means of controlling corrosion. Chemicals that are most used for this purpose include calcium carbonate, silicates and polyphosphate.

The earlier treatment method of coating with calcium carbonate was achieved by adding lime to the water in such a way that the water was deliberately made scale forming, so that calcium carbonate scale would cover the corroding pipe surfaces and stifle the corrosion. Lime addition was sound in theory, but the difficulty experienced in practice was that most of the scale would precipitate in transmission mains leaving the system unprotected and even decreasing flow rates in the distribution system.

The use of a polyphosphate, sodium hexametaphosphate, was introduced for scale prevention in 1938 and helped considerably by keeping transmission mains free of calcium carbonate scale. This innovation at least permitted lime softening plants to send water out at pH values above 10, and such pH values are effective in decreasing corrosion. In latter years the glassy phosphate (sodium hexametaphosphate) was found to be in itself an effective corrosion inhibitor at pH values below 8 and, being non-toxic as well as colorless and tasteless was ideal for use in potable water systems. This discovery led to a development of a bimetallic glassy phosphate (sodium-zinc glassy phosphate) for use in the municipal field.

This complex bimetallic phosphate glass, (containing 8-9% zinc) proved to be three to five times as effective (depending on conditions) as straight sodium phosphate glass in overcoming corrosion in water systems. It required more than 25mg/1 of sodium hexametaphosphate even to approach the effectiveness of the bimetallic glassy phosphate.

Unfortunately, it requires as long as 24 hours to dissolve this bimetallic glassy phosphate in some waters at temperatures above 10°C, and feed solutions of more than 1 per cent (approximates 0.5 kg per 50 liters) are seldom stable. At temperatures below 10°C the material frequently will not dissolve to any noticeable extent. This created some limitations of treatment in the municipal field.

Nevertheless, several hundred municipalities in warmer areas are using bimetallic phosphate glass either to maintain high flow coefficients following mechanical cleaning of mains or to eliminate red water complaints. Continuous dissolving feeders have been used quite effectively, with the rate of dissolution determining the amount fed to the water. These municipalities have obtained superior results in controlling corrosion with one important limitation: the rate of feed must always be sufficient to carry a metaphosphate residual to the ends of the distribution system. In most instances, this minimum proves to be no more than 1 mg/1.

Bimetallic metaphosphate glass has been particularly effective in tuberculation control because of its rapid film formation. When used at a high concentration during an immediately after the cleaning operation, the bimetallic glass overcomes the disadvantage of tubercules being formed before the polyphosphate film can form.

Although greater attention has been given to the use of the bimetallic glassy phosphate in connection with water main cleaning and tuberculation control, equally good results have been obtained in eliminating difficult corrosion problems and red-water complaints when main cleaning is not involved. Actual data of a small municipality which treated 1,877.5 cu m/day by means of conventional clarification - sand filtration plant shows the effect of bimetallic metaphosphate on corrosion. The municipality had a severe corrosion problem resulting in numerous complaints of red waters. The iron content of the water leaving the treatment plant averaged no more than 0.1 mg/1. The water had a pH value of approximately 6.1, hardness of only 16 mg/1 and 15 mg/1 of sulfate ion, however, so that it was quite corrosive. The consumer complaints were definately caused by iron pick-up as the water passed through the distribution system. After treatment by bimetallic metaphosphate test data obtained by subtracting the iron content of the water leaving the treatment plant from the total iron content of the water at the different test locations showed an overall reduction in iron pick-up through the system to be 68 percent.

Sodium-zinc metaphosphate is subject to restrictions in use. At pH values above 8 its effect as a corrosion inhibitor is limited and maximum effectiveness for iron and steel is obtained at pH values between 6 and 7.5. It is true that the bimetallic phosphates are somewhat more effective at higher pH values, but this is difficult to measure. They require, however, a minimum calcium content in the water of at least 1 mg/l (2.5 mg/l hardness) for every four or five mg/l of phosphate for proper film formation; and best results are obtained when the water contains at least 0.017 grams per liter of hardness.

The ground characteristic is a significant factor in corrosion of the outside of the distribution system. The use of corrosion resistant materials, electrolytic protection, and altering the characteristics of the environment (i.e. using special backfill material such as sand or gravel) are used in combating this type of corrosion. Very effective protection of ductile iron pipe under corrosive conditions can be provided by encasing the pipe during installation with a loose tube or sleeve of polyethelene 8 mils thick. This protective method has been tested by the Cast Iron Pipe Research Association over a period of 15 years in several very corrosive sites such as cinders and tidal muck, and found to give excellent protection.

Non-metallic pipes have exhibited potential as water distribution mains in public works. Their use is not innovative as clay tile pipes have been used for many years. In recent years a great deal of attention has been given to plastic pipes. Inert to chemical action of waters and soils, plastic pipes should neither rust, corrode, put, tuberculate, nor dissolve during water service.

Cathodic protection is an electrical method of preventing corrosion. It is used on metallic structures which are in electrolytes such as soil or water. It has had widespread application on underground pipe lines in addition to numerous other underground and underwater structures. It operates by passing direct current continuously from electrodes which are installed in the electrolyte to the structure to be protected. Corrosion is arrested when the current is of sufficient magnitude and is properly distributed. A sacrificial node is substituted which is dissipated instead of the pipeline metal. Where properly applied cathodic protection can completely eliminate the loss of metal and the resulting pitting from underground corrosion. Cathodic protection is most economical where it is used in conjunction with good coatings. The amount of current required is proportioned to the bare area; therefore, the better the coating less current required. Many economic studies have found that the use of cathodically protected coated pipe is the most economical to be used. Cathodic protection, however, exhibits a tendency to have high installation cost and a continuing need for maintenance and technical service.

Much has been done in the design stages to help combat corrosion, an example of which is the installation of insulating joints either to avoid bi-metallic coupling or to confine cathodic protection current.

It is to be noted that each of the corrosion control methods presented here has a number of conditions to consider and many limitations relative to a particular situation. Before adaption of any method the user is urged to carefully scrutinize and identify the particular corrosion problem before proceeding to select a certain protection technique.

Dead Ending

In the design of water distribution systems dead ending should be avoided, unless it is the case where the dead ending becomes unavoidable in the early stages of piping system development. Provisions for circulation or lack of such provisions will have some effect on water quality. This largely depends on the water quality entering the system. Lack of circulation obviously creates dead ends with their variable and somewhat unpredictable problems. Because of the lack of water movement in dead ends, an accumulation of rust, organic matter, and other material can cause undesirable odors, taste and color, which can be drawn throughout the system during periods of low flow.

All dead ends should be routinely inspected and flushed thoroughly to prevent the deterioration of water quality in the system.

Biological Degradation and Infestation

A phenomenon commonly called "aftergrowth" or "secondary growth" often develops in distribution systems even when water at the source meets or exceeds Federal Drinking Water Standards and Guidelines. This contamination by coliform organisms is the most complex and least understood cause of biological infestation. It is not established whether these organisms are from recovery of cells partially injured by treatment, or if they are bacteria that produce any of several types of gases which could be: hydrogen sulfide, carbon dioxide, nitrogen, methane or ammonia. Methods of controlling this problem include: better treatment at the source, elimination of noncirculating zones in the system, and adequate flushing. An important means of controlling aftergrowths is chlorine treatments. It is likely that complete control of coliform aftergrowth is obtained only if chlorine residuals are carried to extremities of a distribution system. This has been accomplished on increasing number of systems, but often with difficulty and with consumer dissatisfaction, at least for an initial period. Chlorine should not be used indiscriminately throughout the distribution system although EPA recommends chlorine residuals throughout the system. Where laboratory analysis shows that water in the distribution system is contaminated, investigations should be made to locate the problem and appropriate corrective steps should be taken.

A number of larger biological forms may find their way into domestic water distribution systems. Broadly these are known as nuisance organisms and include nematodes, snails, the larvae of the chironomid fly, and others. Some authorities also include Crenothrix under the general heading of nuisance organisms. Snails and nematodes are introduced at the source and can best be controlled at that point. Measures for the prevention and elimination of larval infestations may be divided into mechanical, biological and chemical procedures.

Mechanical procedures mainly consist of reservoir protection features and the use of filters placed at the outlet pipe to the distribution system. The latter method has been proved to be effective in some plants throughout the United States. Biological methods of control depend for their success on the interruption in some manner of the development of the insect. Examples of this type of control include such methods as: removing a major source of food supply and strict control of their development in the reservoir. Chemical methods consist of very delicate procedures, and even the most reliable chemical measures available at this time offer only temporary relief, and their application should be limited to extreme emergency situations and with close consultation of public health authorities.

The control of Crenothrix in distribution systems is adequately dealt with in a publication by AWWA.[1] The publication stated:

> "Crenothrix, one of the higher bacteria, is a microscopic, filamentous (threadlike) organism closely related to true bacteria and microscopic fungi. This organism will live in the dark and in the absence of dissolved oxygen but will not thrive in water containing large concentrations of dissolved oxygen. It requires iron as an essential food and thus will live on the inside of distribution systems conducting water containing iron.
>
> Crenothrix will grow in gelatinuous masses on the inside of water mains to an extent that will seriously reduce the capacity of the mains and will lead to the presence of objectionable concentrations of precipitated iron in the water and to objectionable tastes and odors, especially when the organism dies. Its presence is to be anticipated when well water containing iron, but little or no dissolved oxygen, is pumped into distribution systems.
>
> Crenothrix may be eliminated by removing iron (food) from water before it enters distribution systems, by increasing the concentration of dissolved oxygen in the water above about 2.0 mg/l through aeration, and by the application of copper sulfate or chlorine to the water. It is significant to note, however, that the doses of copper sulfate and chlorine required for the rapid destruction of these organisms are higher than may be utilized in the treatment of a potable supply, but fortunately limited doses are effective if continued for a period of several weeks or more. Copper sulfate doses in excess of 0.3 mg/l are effective, and a dose of 0.5 mg/l is recommended. The chemical may be applied with various types of feeders available for applying alum to water.

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[1] Water Quality and Treatment, A Handbook of Public Water Supplies, AWWA, 1971, p. 494. (Ref. 105).

> The chlorine dose required to destroy this organism is that dose necessary to result in a concentration of residual chlorine between 0.5 to 1.0 mg/l. It may be quite difficult to maintain this concentration of residual chlorine unless ammonia is added also to stabilize the chlorine. Even then, objectionable tastes are likely to be produced through the destruction of the organisms, so such treatment should be preceded by a notice to the consumers that special treatment is to be utilized for the destruction of these organisms so they will not be unduly concerned as to the quality of the water supplied to them temporarily."

Quality of Water put into Distribution System

In waterworks it is generally accepted that water leaving the consumer tap will be of lower quality than that entering the distribution system. Therefore, the importance of transmitting high quality water from the treatment plant to the distribution system cannot be neglected. The lower the quality of water put in the distribution system from the treatment plant, the more the problems of contamination within the distribution system will be compounded. The quality of the finished water is a reflection on the quality of the source. Each community should try to select the best possible source in order to avoid excessive stress and shock loads on the treatment plant. Where quality control at the source is not practiced the effects of treatment irregularities are likely to be passed on to the distribution system. Poor watershed control practices will impair the performance of even the most modern and efficient treatment plant by the introduction of shock loads caused by unabated pollution.

Air Relief Valves and Blowoffs

Proper location of air valves and blowoffs are imperative in order to prevent the entrance of contaminated or polluted water when they are open. Air valves are used to relieve entrapped air. They aid in the prevention of milky water when lines are at full capacity. Vacuum-release valves are used to allow air to enter lines that are unable to withstand atmospheric pressure when under vacuum. Vacuum valves have been known to leak under very low head and if proper drainage is not provided and maintained the valve could become submerged with water and allow pollution of the distribution system. Blowoffs are normally located at a low point for draining a line or for connecting a line, however, they should also be provided where no other means of blowing off a dead end exists. Water quality is not directly affected by blowoffs, but their presence is necessary to permit blowing off a line, which gives temporary relief to a poor-quality water condition. Direct connection of blowoffs to sewers and manholes must never be allowed.

Sampling of Distribution System

To efficiently maintain good quality water in the distribution system it is expedient to institute an effective sampling program. Federal Drinking

Water Standards and Guidelines have established recommendations for sampling water quality in distribution systems.

The more salient concern of the standards is bacteriological quality - more specifically, with coliform organisms. Realizing that varied nature of different distribution systems makes it difficult to establish specific requirements for sampling, the standards therefore, are very general in their recommendations. It is urged that all municipalities adhere to the Federal Drinking Water Standards and Guidelines when instituting a sampling program. This program is necessary to provide a continual feedback of water quality in the distribution so analyses can be made and any problems in the systems can be effectively dealt with.

SECTION VII

TREATMENT PROCESS SELECTION AND EFFECTIVENESS

a. Process Selection

The bases for selection of the optimum treatment system are the source water quality, the desired product water quality, and the capacity of the plant, and type of existing facilities. The cost and location of the facilities will also influence the design.

The required capacity of the plant will often influence the selection of unit operations. Some processes are more economical than others at small capacities, whereas as the capacity increases, the economics may tend to favor alternate processes. The flexibility of the chosen system to meet variations in source water quality and in consumer demand is also an important design criteria. Ease of operation, and the minimum requirement for maintenance operations have substantial bearing upon the selection of the treatment system in locations where there may be a shortage of skilled labor.

All of these factors, however, are peculiar to a specific set of circumstances, and may not readily be quantified on a general basis. The effectiveness of a given process for the removal of a specific contaminant, or groups of like contaminants, can be quantified, and can form an excellent method for further investigations or comparative studies.

It is extremely difficult to simplistically state the effectiveness of a process for the removal of a specific contaminant. The level of removal depends on a variety of physical and chemical parameters, all of which must be considered for each specific case. However, for planning purposes, the effectiveness of the treatment methods can be approximated closely enough to provide the necessary information for process selection. It must be emphasized that extensive laboratory and/or field tests on the subject source water must be performed before final decisions on the treatment system can be made.

Aeration

1. Odor removal is better than 90% in some cases, except for odor-causing compounds such as chlorophenols, however the effectiveness is variable. Acidification or the use of carbon dioxide in the aeration column may be necessary for the complete oxidation of hydrogen sulfide.

2. Iron and Manganese are oxidized to the insoluble trivalent forms, which are precipitated, and may be removed by sedimentation or filtration. Ninety percent removal is possible, but concentrations about 1.0 mg/l of iron may require pre-oxidation using chlorine.

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Sedimentation

1. Turbidity. Turbidity caused by heavy silt particles may be removed by plain sedimentation followed by sand filtration. Sedimentation alone is not suitable for turbidities of greater than 20 JTU, and is usually employed with coagulation. Extremely muddy waters may be presettled, but would require additional treatment. The reduction in turbidity by plain sedimentation cannot be predicted, and must be evaluated on an individual basis.

Coagulation and Sedimentation

1. Turbidity is almost totally removed by coagulation and sedimentation. If the process is followed by rapid sand filtration, turbidity reduction approaches 99%. Without filtration, reductions are of the order of 80%.

2. Color removal is of the order of 95% if sand filtration is used for polishing.

3. Arsenic has been removed successfully in bench-scale apparatus by coagulation with a high level of alum (hydrated aluminum sulfate) followed by sedimentation and sand filtration. The best results were obtained at an initial pH of 6 with 50 mg/l of alum - removal efficiency approached 94%. Substituting hydrated ferrous sulfate for alum at the same pH, and with 40 mg/l dosage removed 99%+ of arsenic (V).

4. Mercury. Extensive laboratory work by Logsdon and Symons has indicated that substantial reductions in mercury levels (See mercury - Section II) may be expected using coagulation and sedimentation techniques. Very broadly, alum coagulants will reduce mercury about 30%, and iron coagulants will reduce mercury 40-60%. No operational tests on full size equipment have yet been performed.

5. Selenium. Coagulation with ferric sulfate will remove 60% to 90% of Selenium IV with a pH of <7, and 30% of Selenium VI. Alum coagulation will remove 0 to 30% of both IV and VI.

6. Radioactive Contaminants. Coagulation and sedimentation will remove 20 to 80% of alpha emitters, depending upon the specific type. Radium 226 will be removed up to 25%.

   Beta emitters will be 20 to 80% removed. Strontium 90 will be 80% removed, while Iodine 129 and 131 will be 20% removed.

Rapid Sand Filtration

1. Bacteria will be removed by rapid sand filtration, if included in or attached to particles of suspended or colloidal matter.

2. Turbidity will be 99% removed in a rapid sand filter, if the influent turbidity is less than 15 JTU. However, frequent backwashing will be required for the filtration efficiency of the bed.

3. Arsenic can be oxidized by chlorine, absorbed on ferric chloride, and removed in a sand filter. Pilot scale tests show removal efficiencies of 99%+ with As^{5+} concentration in raw water of less than 1.0 mg/l, and dosage of 30 to 60 mg/l of ferric chloride. The filter is washed with caustic soda and arsenic free water.

Slow Sand Filtration

1. Bacteria removal of 85 - 90% can be effected.

2. Turbidity reduction in the order of 90% is possible, but flow rates must be precisely controlled, and frequent backwashing is required.

3. Colloidal color can be biologically removed. Efficiency varies with the type of color, and the turbidity of the raw water.

Diatomaceous Earth Filtration

1. Bacteria, color and turbidity will be removed to approximately the same level as with slow sand filters given the same raw water characteristics.

2. With preoxidation, manganese can be removed to below the allowable concentration. With preaeration and alkalinity adjustment, iron can be removed to below the allowable concentration.

3. Conversion of soluble mercury to the insoluble form, followed by diatomaceous filtration can reduce mercury levels by 99%+.

Microscreening

1. Bacteria removal of approximately 50% can be expected.

2. Suspended solids removals of 50 to 80% are possible, with minimum screen opening of 23 microns.

Reverse Osmosis

1. Bacteria will be 99%+ removed assuming the integrity of the membrane is maintained, and the membrane material is inert from bacterial attack. Cellulosic membranes are not suitable.

2. Removes color caused by organic materials of molecular weight greater than 200.

3. Cyanide and Fluoride can be removed by 90%.

4. Inorganics can generally be removed by 90 to 97%, providing the concentration factor does not result in calcium precipitation. pH must not exceed 9, otherwise hydrolysis of the membrane will occur.

Electrodialysis

1. All inorganics can be removed by approximately 80%, provided the calcium concentration does not exceed the solubility limits.

Distillation

1. All inorganics will be rejected in the distillate to a level of 99%+. The heat required for distillation will kill some bacteria, but the level varies with the characteristics of the water supply.

Ion Exchange

1. Waste waters from dye plants and food processing facilities have been completely decolored with special resins.

2. 95%+ removal of Barium, Cadmium and Arsenic is possible with ion exchange.

3. Chromium, Copper and Lead can be removed by ion exchange by 95%.

4. The acid radicals, chloride, sulfate and nitrate can be exchanged to a level of 97%+, depending on the level of regeneration.

5. Radioactive contaminants. Alpha emitters can be reduced by 96%+. Strontium 90 has been reduced by 99.9%. However, the water containing the contaminant was ultra pure.

Disinfection

1. Bacteria kill is 99%+ with both chlorine and ozone.

2. Organic color can be 99%+ removed with ozone.

3. Both chlorine and ozone will oxidize iron and manganese for removal by sedimentation and/or filtration.

b. Unit Cost Curves

Unit Cost curves for each process have been developed and presented in Section VII. These curves are based on the following information derived in agreement with the Water Quality Office, Environmental Protection Agency, and Environmental Planning and Engineering Division of David Volkert & Associates.

i. 40 year plant life (30 years for desalting systems)

ii. 6% interest rate

iii. Land cost of $25,000/hectare
(approx. $10,000/acre)

iv. Power cost of 1¢/kwh

All Unit Cost Curves presented here are developed from the cost data presented in Section IV. They are intended to be used only as a very preliminary estimate of the unit cost of water using a particular treatment on a once through basis, since they are of necessity based on the specific restraints described with each curve. If interest rates, power cost, etc. varies significantly, the curves become misleading.

Note that the maximum concentrations given in the following tables are for a single pass through the process listed. The percentage of contaminant removed by each process is an indication of effectiveness, but should not necessarily be used to determine the maximum concentration. The maximum removal rate does not necessarily occur at maximum concentration. Many processes will remove contaminants very effectively up to a certain concentration, and then the rate of removal will drop or decrease rapidly.

For example, the 1974 Federal Drinking Water Guidelines and Standards limit for arsenic is 0.1 mg/l. Preoxidation, coagulation with $Fe\ CL_3$ and filtration have the capability to remove 99% of the arsenic content in water. However, this does not mean that it will be effective at arsenic concentrations of 10 mg/l, since it is about 1 mg/l in practice. Note that if 1 mg/l arsenic is present in the raw water, that these processes will reduce it to well below acceptable levels. If the concentration is higher than 1 mg/l in the raw water, the additional process of chlorination may be necessary. The percentage removal figures can, of course, be used as long as one remains below the maximum concentrations or to indicate if several passes or a combination of processes will be required. For example, if arsenic levels in the raw water are 15 mg/l, then preoxidation, coagulation with $Fe\ Cl_3$, chlorination, filtration, and a desalting process such as electrodialysis or reverse osmosis may have to be coupled into a unit process train.

When a range of values for percentage removal or maximum concentration are given, then the effectiveness of the treatment process is dependent on other factors. These factors may include pH level, particle size, saturation levels, water temperatures, etc.

TREATMENT	CONTAMINANT	%REMOVAL	MAXIMUM* CONCENTRATION	NOTES
AERATION	Odor	90	-	
	Iron & Manganese	90	3.0 mg/1 Fe 0.5 mg/1 Mr	Will remove iron and manganese bicarbonates, must be followed by sedimentation and filtration. Chemical precipitation required for organic bound iron.
SEDIMENTATION	Bacteria	0-90	-	Not sufficiently reliable to meet public health standards. Disinfection required.
	Turbidity	50-95	20 JTU	Minimum efficiency dependent on particle size. Generally used in conjunction with coagulation if turbidity is higher than 20 JTU.

* Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 General Removal of Contaminants by Treatment Processes. See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
COAGULATION	Bacteria	0-90	-	If bacteria attached to colloidal matter. Disinfection required.
	Color	95	300 color units	Followed by filtration. Requires pH of 4 to 6. pH must be raised above 6 before filtration.
	Turbidity	80-99	5-100 JTU	Followed by filtration
	Arsenic	90-99	1 mg/1	With preoxidation, followed by coagulation with $FeCl_3$ and filtration
		99	10 mg/1	With $FeCl_3$ coagulation, chlorination, and filtration
	Cadmium	50-90	0.02-0.1 mg/1	With sedimentation and filtration.
	Fluoride	90	10 mg/1	Alum coagulation

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes. See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
COAGULATION with SEDIMENTATION	Iron & Manganese	90-99	20 mg/l	Followed by filtration. pH must be adjusted to 9.4. Addition of 1 mg/l alum necessary in 10-20 mg/l range.
	Mercury	30	0.0028 mg/l	With alum coagulant
		40-60	0.003-0.006 mg/l	With Fe salt coagulant Above are bench scale test results.
	Turbidity	80-99	100 JTU	Use higher efficiency if followed by filtration.
	Arsenic	see discussion in Section II		
	Cadmium (insoluble)	50-90	0.02-0.1 mg/l	If in insoluble form follow with filtration
	Chromium	50-90	0.1-0.5 mg/l	If in insoluble form follow with filtration
	Selenium	60-90	.03-0.1 mg/l	For Se^{+4}
		0-30	.015 mg/l	For Se^{+6}
	Gross Alpha Radioactivity	20-80	18-75 pCi/l	Followed by filtration. Efficiency dependent on Alpha radioactive source. Pilot studies required to determine specific removal levels.
	Radium 226&228	25	6.6 pCi/l	
	Gross Beta Radioactivity	20-80	1250-5000 pCi/l	See note for Gross Alpha & radioactivity

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication or processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes.
See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
RAPID SAND FILTRATION	Bacteria	0-99	-	Disinfection still required.
Note: rapid sand filtration normally used in conjunction with coagulation and sedimentation				
SLOW SAND FILTRATION	Bacteria	85-99	-	Disinfection still required.
	Color	-	-	See Coagulation.
	Turbidity	80-99	5-100 JTU	5JTU limit. 100 JTU if used after coagulation.
	Iron	90	3.0 mg/1 Fe	
	Manganese	90	0.5 mg/1 Mn	
Note: slow sand filtration normally used in conjunction with coagulation and sedimentation				
DIATOMITE FILTRATION	Bacteria	85-90	-	Disinfection still required.
	Color	50-95	30-300 color units	Dependent on source of color.
	Turbidity	80-99	5-100 JTU	5 JTU limit. 100 JTU if used after coagulation.
	Iron	see note	see note	With preaeration and alkalinity adjustment can lower level to 0.1 mg/1.
	Manganese	see note	see note	With preoxidation using potassium permanganate can lower to 0.05 mg/1
	Mercury	99+	-	Lower Hg levels to 0.004-0.006 mg/1 Additional treatment necessary.

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes. See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
MICROSCREENING	Bacteria	50	-	Disinfection required.
	Turbidity	50-80	2-5 JTU	
REVERSE OSMOSIS**	Bacteria	99+	-	Noncellulosic membrane must be used.
	Color	99+	1500 color units	If color producing material has molecular weight greater than 200.
	Arsenic	90-97	1.0-3.3 mg/1	
	Barium	90-97	10-33 mg/1	
	Cadmium	90-98	0.1-0.5 mg/1	
	Chromium	90-97	0.5-1.5 mg/1	
	Fluorides	90-97	11-60 mg/1	
	Copper	90-97	10-33 mg/1	
	Cyanide	90-97	2-7 mg/1	
	CCE	99	70 mg/1	If molecular weight exceeds 200.
	Lead	90-99	0.5-5.0 mg/1	
	Iron	90-99.5	3-30 mg/1	
	Manganese	90-99.5	0.5-5 mg/1	
	Mercury	90-97	0.02-0.06 mg/1	
	Nitrates (as N)	90-97	100-330 mg/1	
	Selenium	90-97	0.1-0.3 mg/1	
	Silver	90-97	0.5-1.5 mg/1	
	Sodium	90-99	no limit	**note pH must be less than 9 for removal of inorganic ions. Exact removal efficiency dependent on total water chemistry.
	Sulfates	99	2500 mg/1	
	Zinc	90-99	50-500 mg/1	
	General Organic Pesticides	99+	unknown	
	Organophosphates	99+	unknown	

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes.
See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
ELECTRODIALYSIS**	Arsenic	80	0.5 mg/1	
	Barium	80	5.0 mg/1	
	Cadmium	80	0.05 mg/1	
	Chromium	80	0.25 mg/1	
	Fluorides	80	5.0-9.0 mg/1	Dependent on temperature of water.
	Copper	80	5.0 mg/1	
	Cyanide	80	1.0 mg/1	
	Lead	80	0.25 mg/1	
	Iron	80	1.5 mg/1	
	Manganese	80	0.25 mg/1	
	Mercury	80	0.01 mg/1	
	Nitrates (as N)	80	50 mg/1	
	Silver	80	0.25 mg/1	
	Selenium	80	0.05 mg/1	
	Sodium	80	no limit	
	Sulfates	80	1,250 mg/1	
	Zinc	80	25 mg/1	

Note:**Inorganic ion removal efficiency dependent on calcium ion concentration in raw water. Presoftening will produce maximum efficiency, if necessary.

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes. See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM * CONCENTRATION (mg/1)	NOTES
DISTILLATION**	Arsenic	99.9	100	
	Barium	99.9	1,000	
	Cadmium	99.9	10	
	Chromium	99.9	50	
	Fluoride	99.9	1,000	
	Copper	99.9	1,000	
	Cyanide	99.9	200	
	Lead	99.9	50	
	Iron	99.9	300	
	Manguanese	99.9	50	
	Mercury	99	0.2	
	Nitrates	99.9	10,000	
	Selenium	99.9	10	
	Silver	99.9	50	
	Sodium	99	12,000	
	Sulfates	99.9	250,000	
	Zinc	99	500	

**distillation, of course, is used to desalt seawater. Virtually any salt concentration can be handled.

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes. See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
ION EXCHANGE	Color	100	-	Special resins will remove organic dyes, humates and legates.
	Arsenic	95	2.0 mg/1	
	Barium	95	20.0	
	Cadmium	95	0.2	
	Chromium	95	1.0 mg/1	
	Fluorides	95	22-36 mg/1	Dependent on water temperature.
	Copper	95	20.0	
	Cyanides	95	4.0	
	Lead	95	0.1	
	Iron	95	6.0	
	Mangunese	95	0.1	
	Mercury	95	0.04	
	Nitrates (as N)	97	200	
	Selenium	95	0.2	
	Silver	95	0.1	
	Sodium	95	no limit	
	Sulfates	97	5,000	
	Zinc	95	100	
	Radium 226&228	96.8	160 pCi/liter	With zeolite beds for water of high purity. If other contaminants are present, efficiency may be much lower
	Strontium 90	95	160 pCi/liter	

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes.
See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
CHLORINATION	Bacteria	99+	-	
	Odor	90	-	Superchlorination followed by excess chlorine removal. Activated carbon treatment may also be required.
	Arsenic	99	10 mg/l	With iron salt coagulation and filtration.
OZONATION	Bacteria	99+	-	
	Odor	90	-	May produce bad taste while curing odor problem. Activated carbon treatment may be re-required.
ACTIVATED CARBON	Odor	100	-	
	Color	100	-	
	Foaming Agents	90-100	5.0 mg/l	As Methylene-Blue active substances.
	CCE	50-99	1.4-70 mg/l	Lab testing required.
	Mercury	-	-	See figures Hg-8, and Hg-9.
	General Organic Pesticides	99+	-	Lab testing required.
	Organophosphates	50-99+	-	Lab testing required.

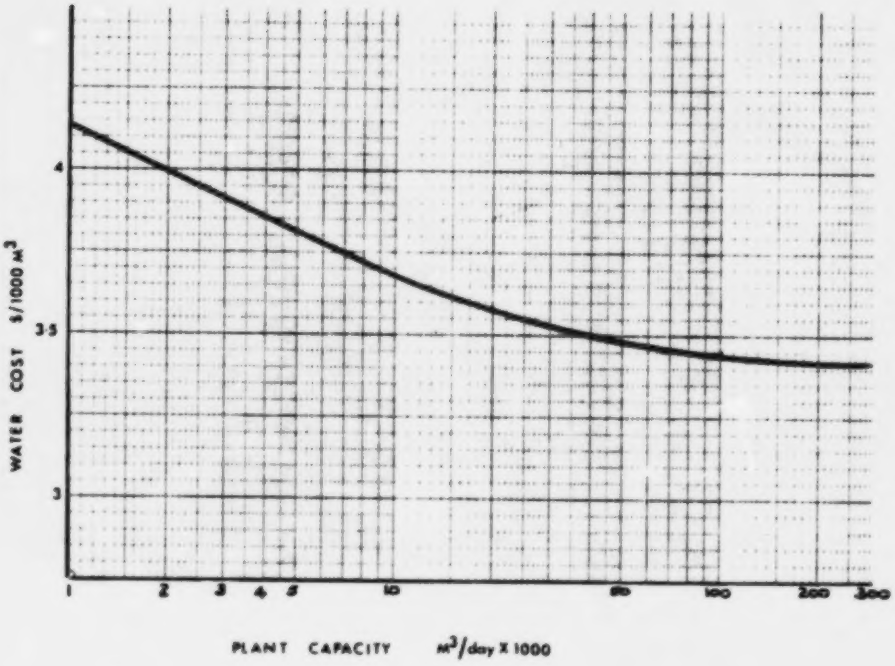
*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher, then combination or duplication of processes or other processes must be considered.

TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes. See Text in Section VII for additional information.

TREATMENT	CONTAMINANT	% REMOVAL	MAXIMUM* CONCENTRATION	NOTES
LIME SOFTENING	Mercury	60-80	0.01 mg/1	Bench scale testing
	Radium 226&228	75	20 pCi/1	
LIME SODA SOFTENING	Arsenic	90	1.0 mg/1	Effectiveness at As concentrations 0-1.0 mg/1 and pH 9.5 to 10
		60	see note	Effectiveness drops at concentrations between 1.0-10 mg/1 and pH 9.5 to 10. Additional treatment necessary.
		90	10 mg/1	pH 10.6-11. Additional treatment necessary if As concentrations exceed 1.0 mg/1.
	Selenium	60-90	.025-0.1 mg/1 0-.015 mg/1	Se^{+4} pH 10.6 to 11. Se^{+6} pH 10.6 to 11.
	Strontium	96	200 pCi/1	For water of high purity. If other contaminants exist, efficiency may be much lower.
	Fluoride	90	10 mg/1	Using crushed dolomite limestone.

*Maximum concentration in raw water, which can be reduced to 1974 Standards and Guidelines in a single pass through process. If raw water concentrations are higher then combination or duplication of processes or other processesmust be considered.

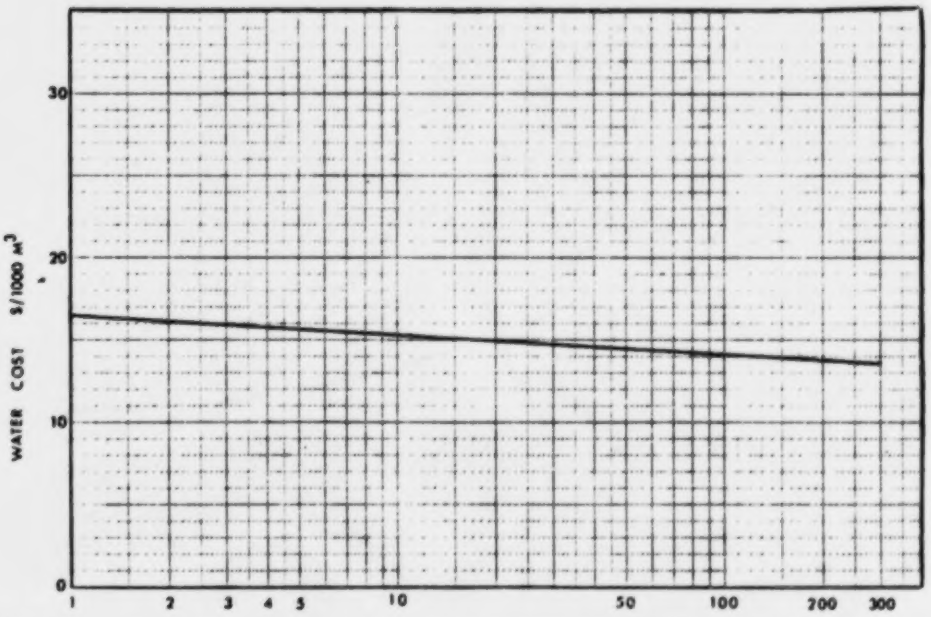
TABLE VII-1 Continued General Removal of Contaminants by Treatment Processes.
See Text in Section VII for additional information.



Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6%/yr.) on cost of working capital. Operating and Maintenance costs including taxes, insurance, labor, power, etc.; land requirement negligible.

Source: Environmental Planning and Engineering Division

Figure UC-1 - Aeration

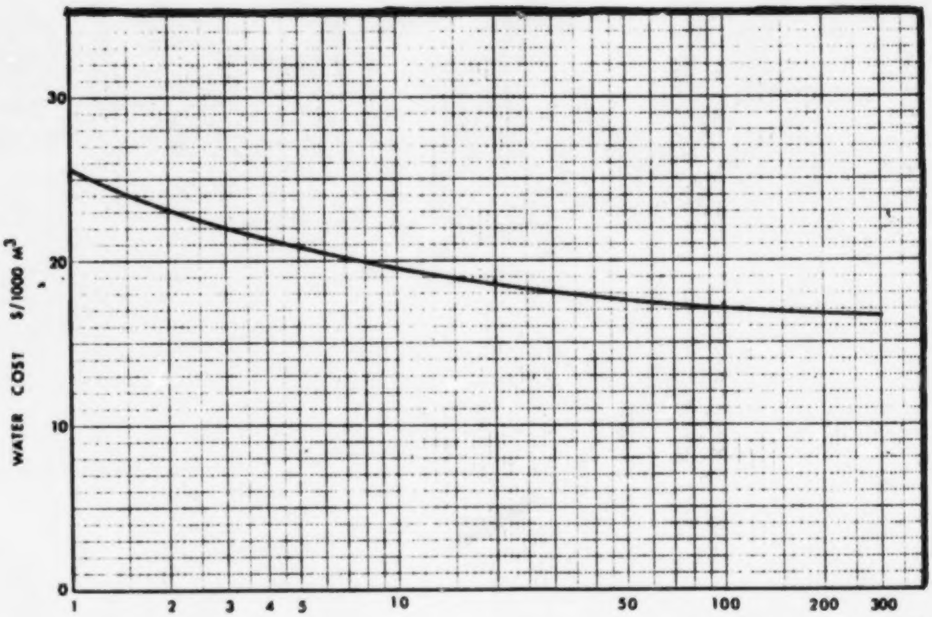


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc.

Source: Environmental Planning and Engineering Division

Figure UC-2 - Sedimentation

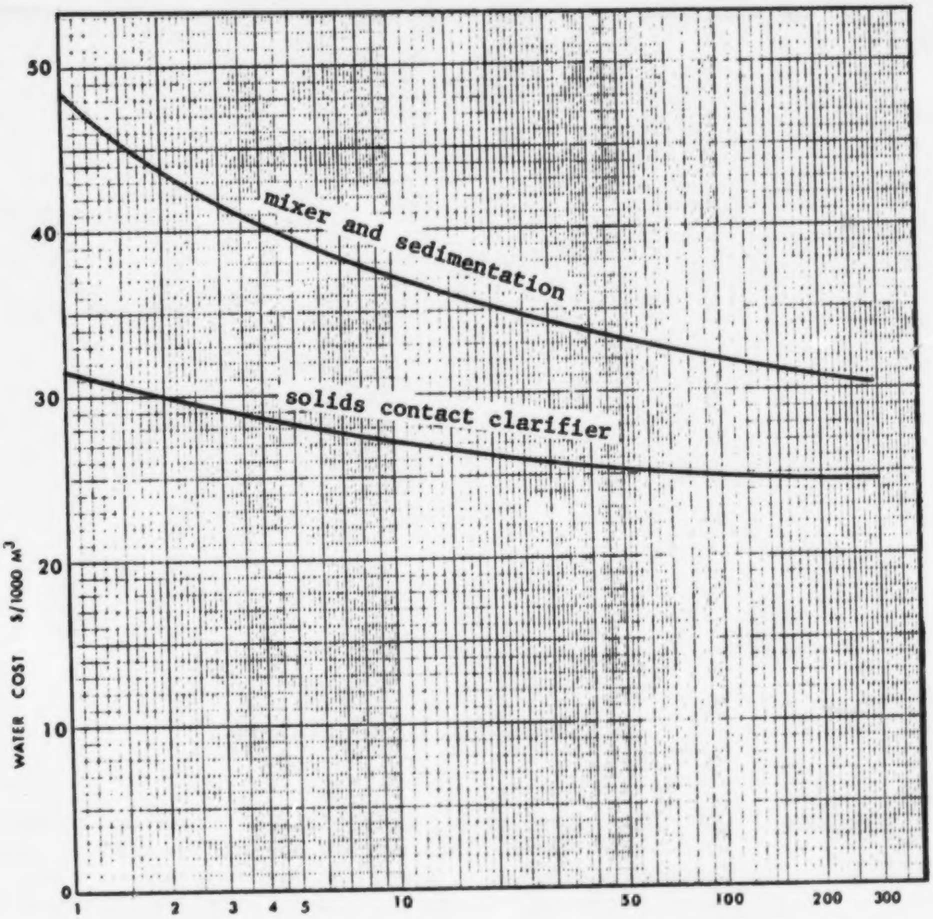


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc.

Source: Environmental Planning and Engineering Division

Figure UC-3 - Coagulation

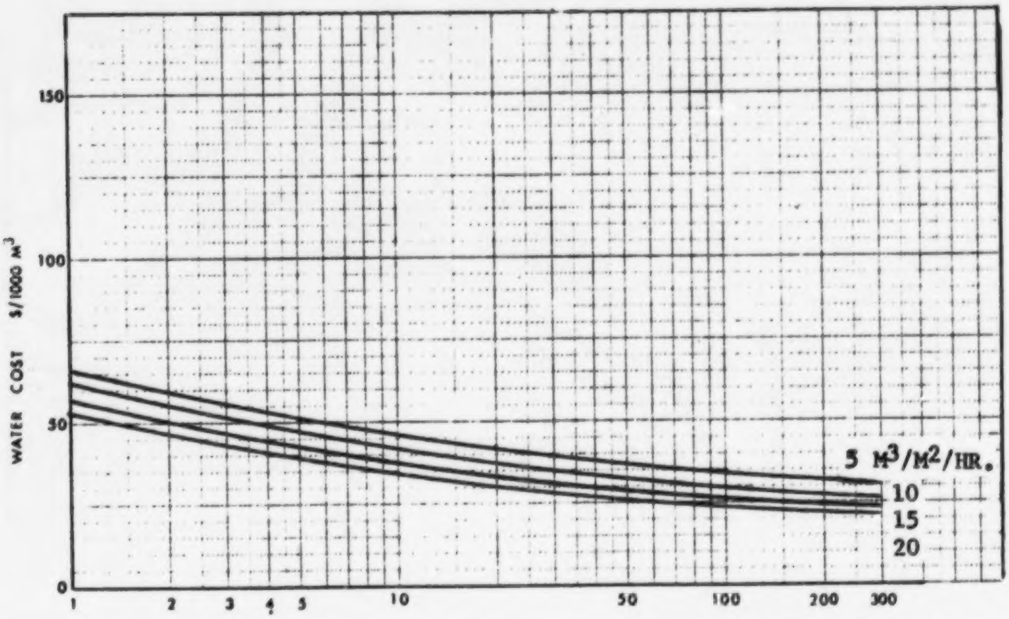


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc.

Source: Environmental Planning and Engineering Division

Figure UC-4 - Coagulation and Sedimentation

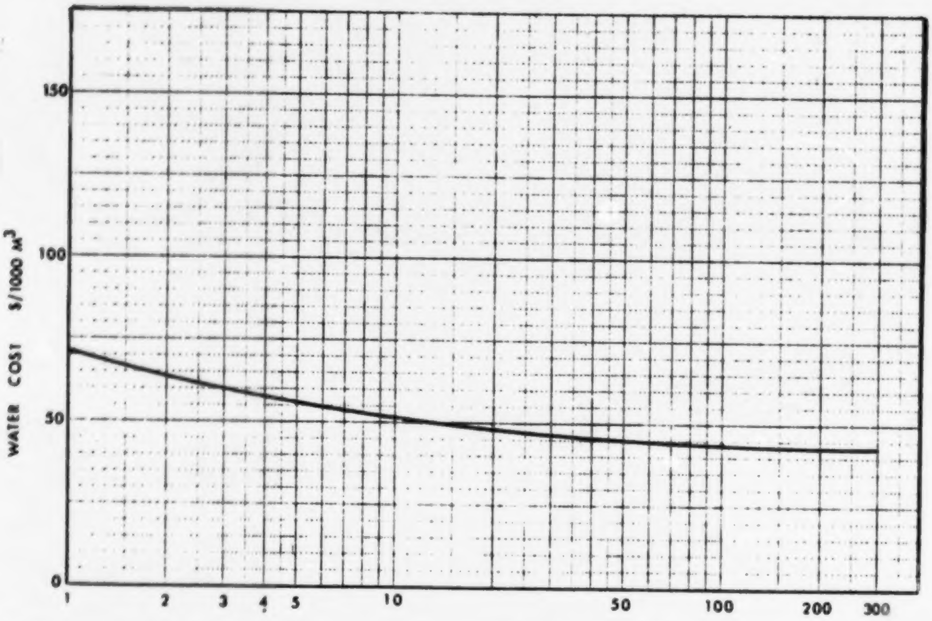


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc.

Source: Environmental Planning and Engineering Division

Figure UC-5 - Rapid Sand Filtration

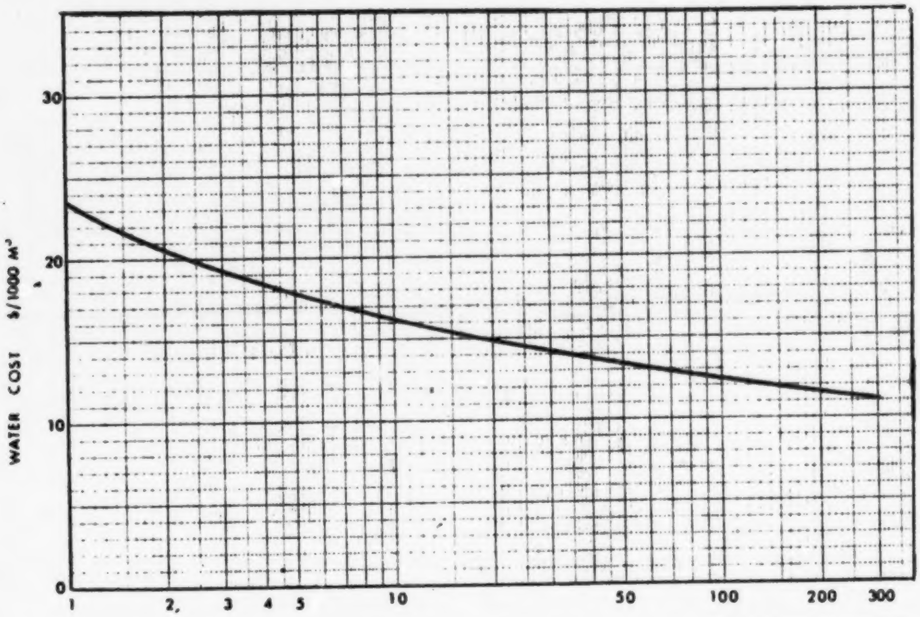


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc.

Source: Environmental Planning and Engineering Division

Figure UC-6 - Slow Sand Filtration

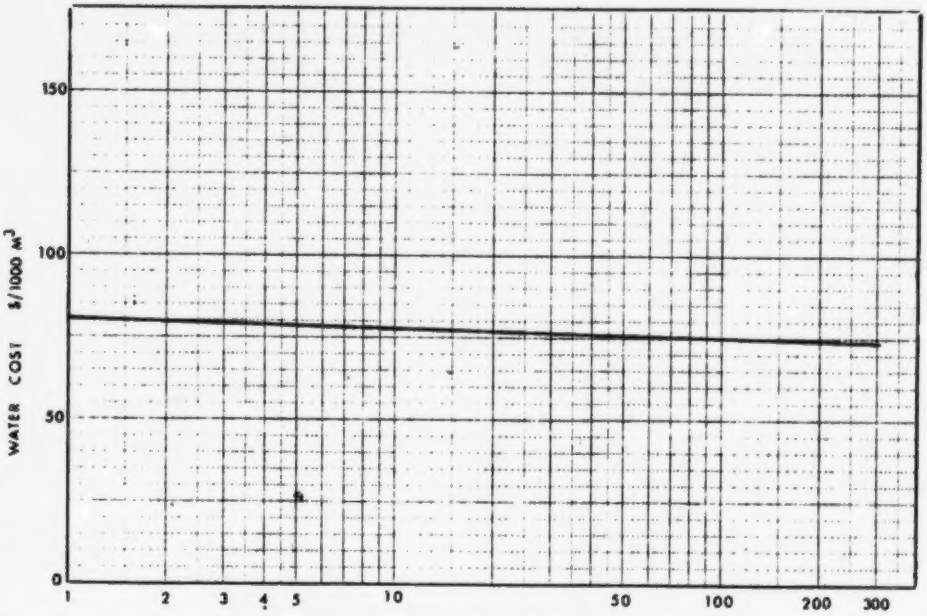


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies (2% of construction cost), chemicals, power, etc.

Source: Environmental Planning and Engineering Division

Figure UC-7 - Diatomaceous Earth Filtration

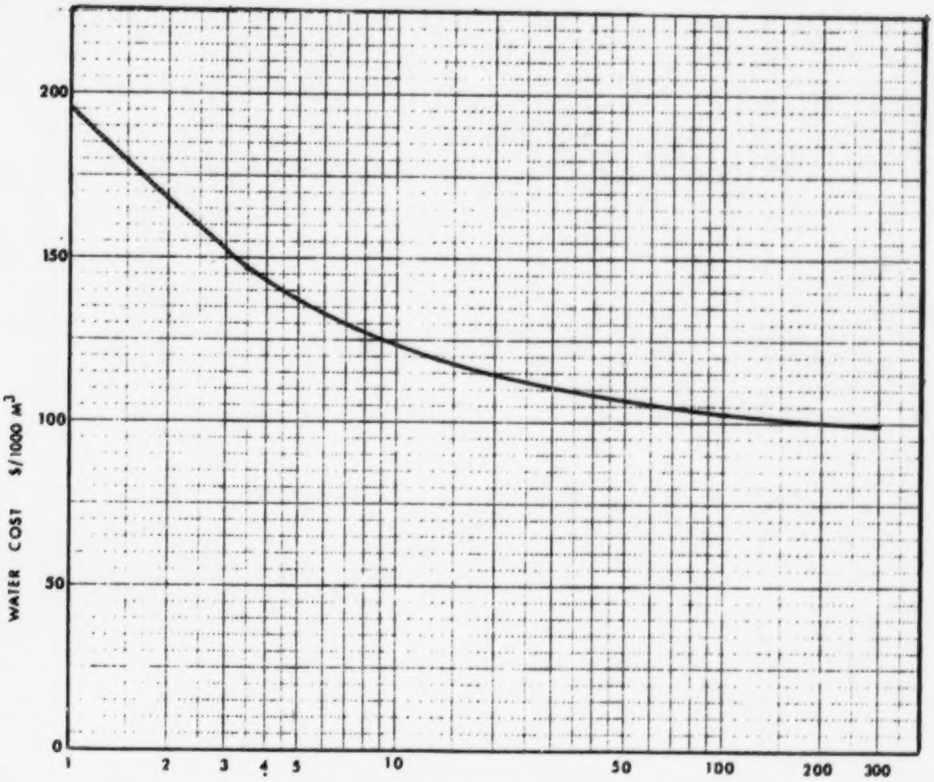


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (6%/yr.) on cost of working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc.; land requirement negligible.

Source: Environmental Planning and Engineering Division

Figure UC-8 - Microscreening



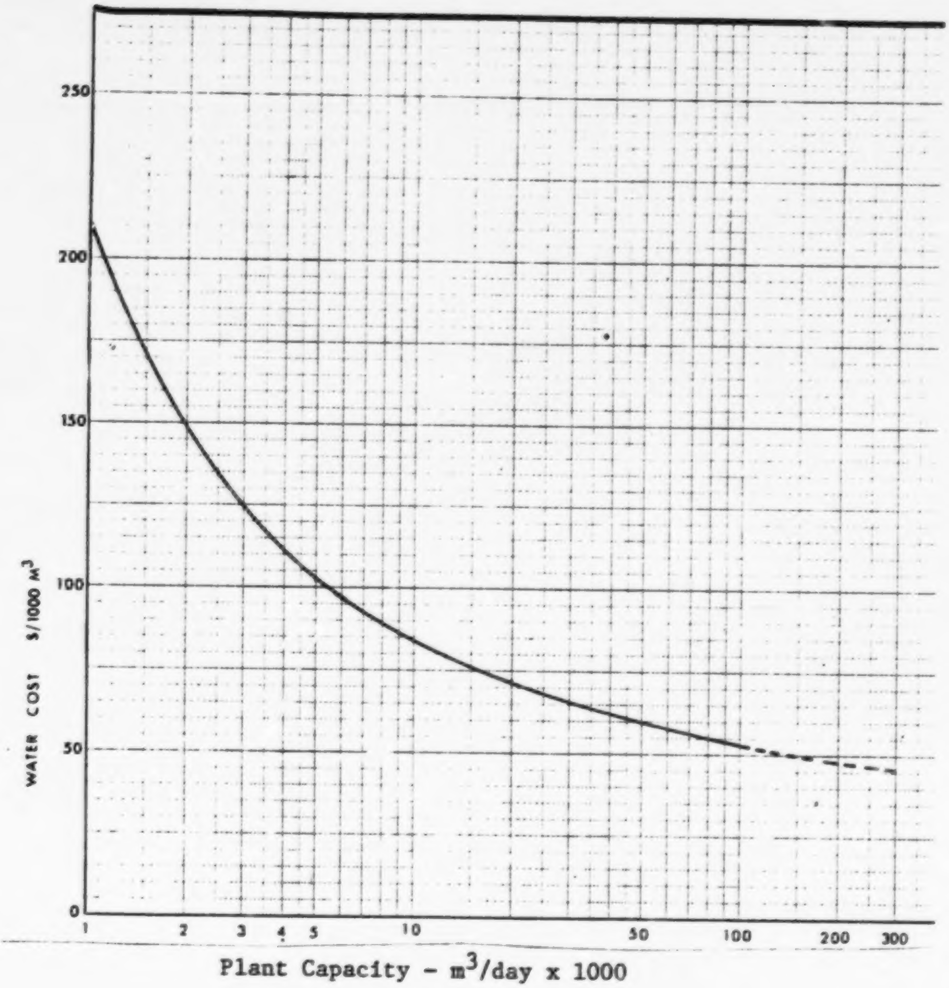
Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs over a 30 year term.

Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power membrane replacement, etc.

Source: Environmental Planning and Engineering Division

Figure UC-9 - Reverse Osmosis



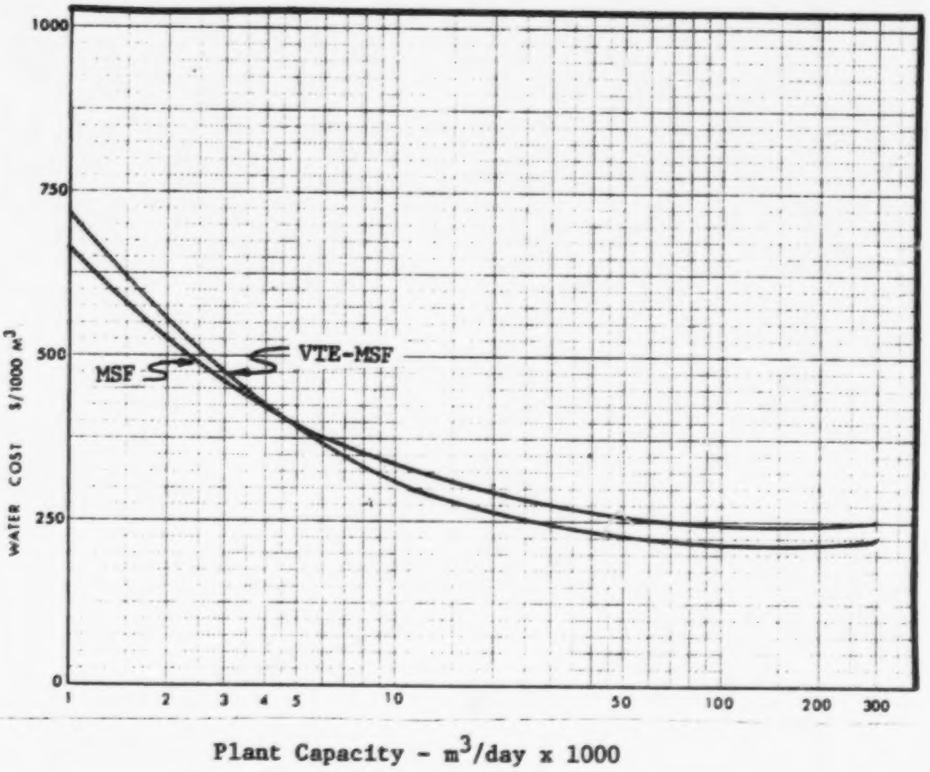
Includes: Amortization of site preparation and construction costs over a 30 year term.

Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies (1% of construction cost), chemicals, power and membrane replacement.

Basis: Raw water 1311 mg/l concentration TDS, product TRS 500 mg/l, temperature 25°C.

Source: Environmental Planning and Engineering Division

Figure UC-10 - Electrodialysis

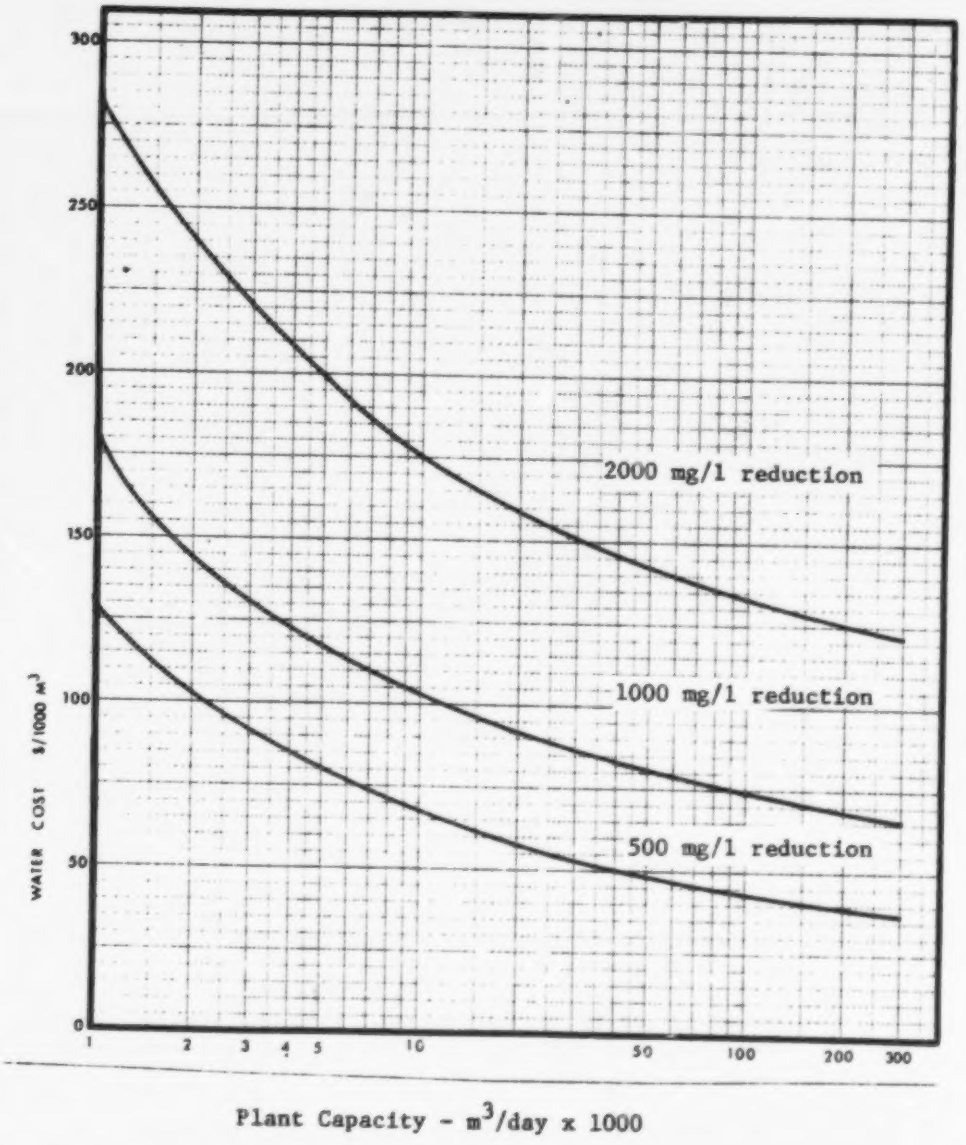


Includes: Amortization of site preparation and construction costs over a 30 year term.

Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc.

Source: Environmental Planning and Engineering Division

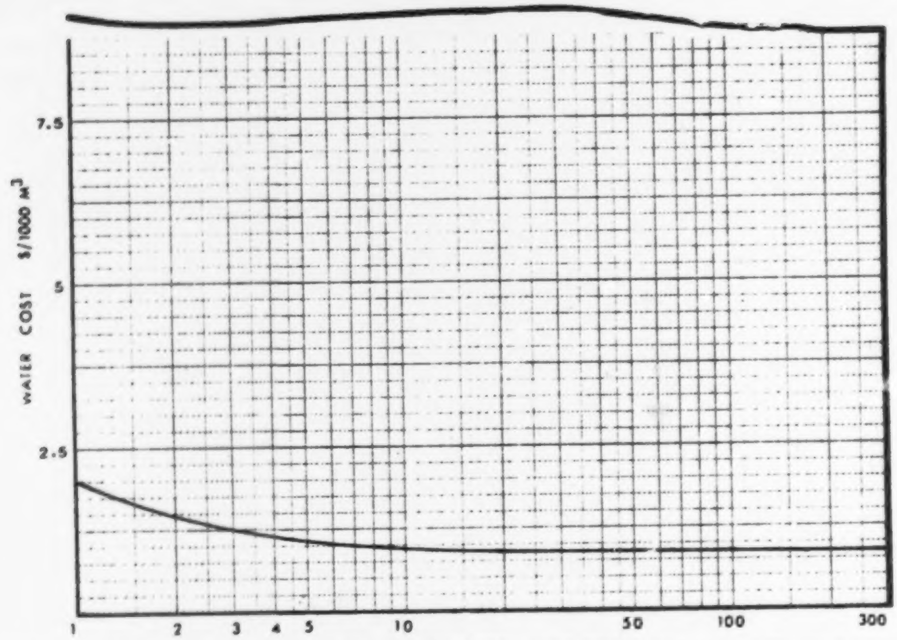
Figure UC-11 - MSF and VTE-MSF Distillation



Includes: Amortization of site preparation and construction costs over 30 yr. term. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, resin replacement, etc.

Source: Environmental Planning and Engineering Division

Figure UC-12 - Ion Exchange



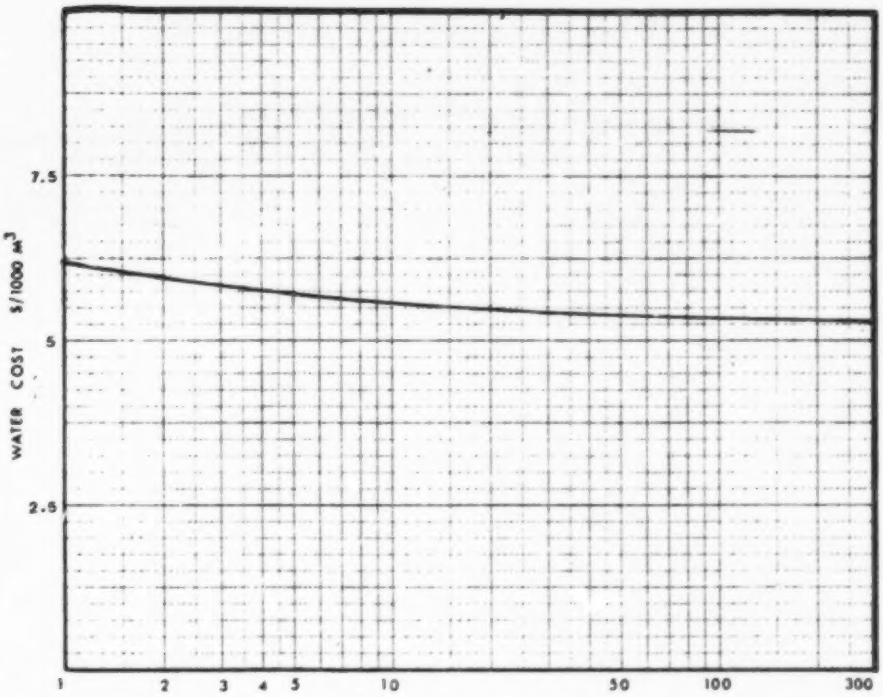
Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation equipment and construction costs.

Interest (at 6%/yr.) on cost of working capital. Operating and Maintenance costs including taxes, insurance, and chlorine gas at 11¢/kg. Includes cost of maintaining equipment.

Source: Environmental Planning and Engineering Divison

Figure UC-13 - Chlorine Gas Disinfection

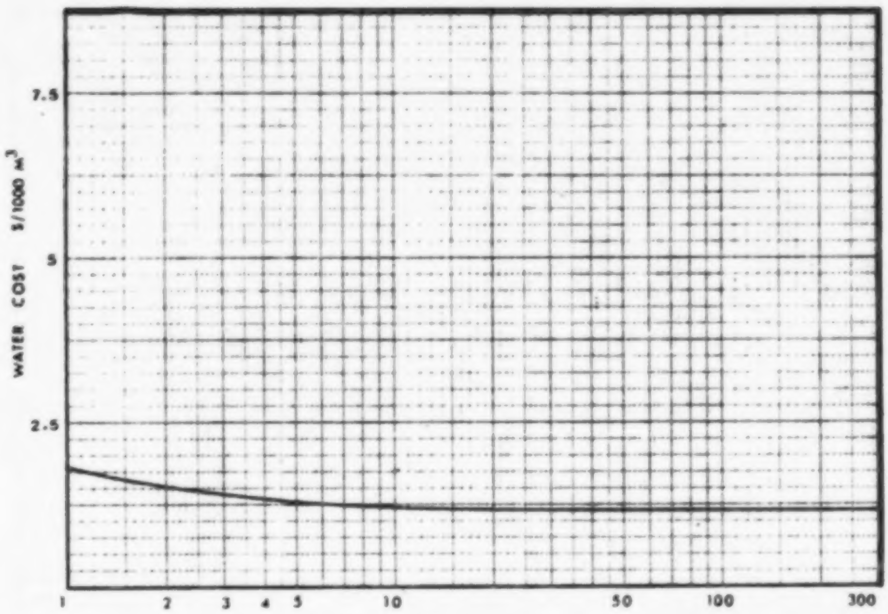


Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction costs. Interest (at 6%/yr.) on cost of land and working capital. Operating and Maintenance costs including taxes, insurance, labor, supplies, chemicals, power, etc. Includes cost of maintaining equipment.

Source: Environmental Planning and Engineering Division

Figure UC-14 - Site-Generated Hypochlorite Disinfection



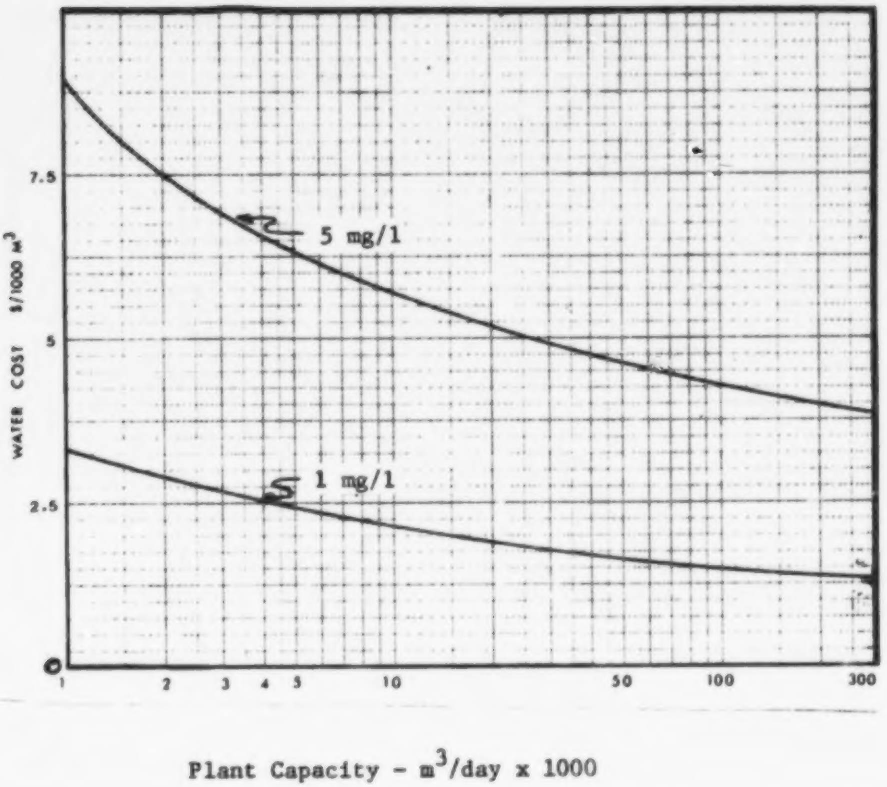
Plant Capacity - m^3/day x 1000

Includes: Amortization of site preparation and construction cost. Interest (at 6%/yr.) on cost of working capital.

Operating and Maintenance costs including taxes, insurance, and sodium hypochlorite at 12¢/liter. Includes cost of maintaining equipment.

Source: Environmental Planning and Engineering Division

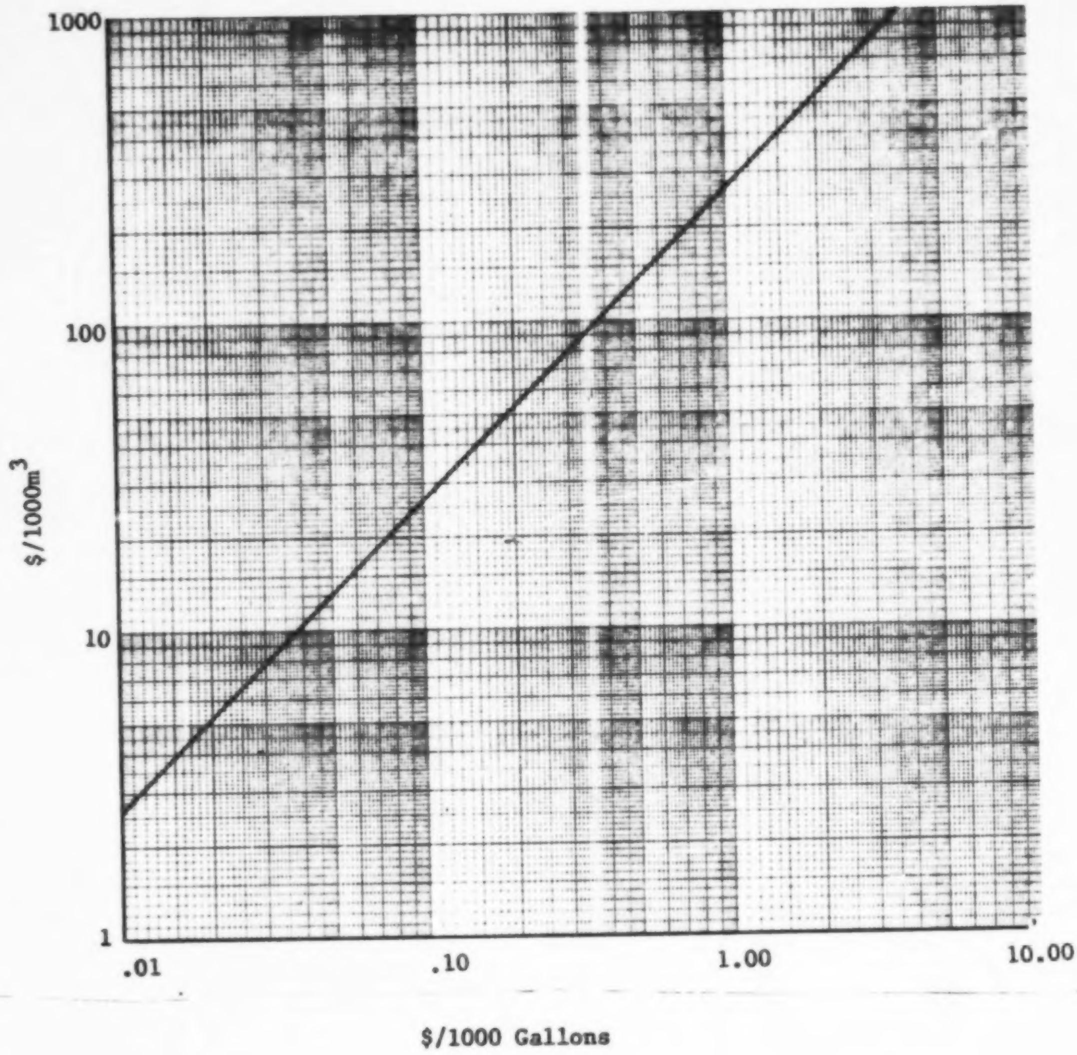
Figure UC-15 - Sodium Hypochlorite Disinfection



Includes: Amortization of site preparation and construction costs over 40 yr. term. Interest (at 6% yr.) on cost of working capital. Operating and Maintenance cost primarily power.

Source: Environmental Planning and Engineering Division.

Figure UC-16 - Ozonation



Source: Environmental Planning and Engineering Division.

Figure UC-17 - Unit Cost Conversion Cost

SECTION VIII

EXAMPLE PROBLEMS

Cost estimates can be obtained for the treatments listed elsewhere in this report. The curves and tables in this report can be considered as guidelines and any futher information available to the estimator can be used to supplement his estimate. Cost estimates prepared from this report should be used only for comparison studies, preliminary economic analysis and to assist in selection of processes, and not for detailed cost negotiations or funding.

Capital costs refer to all costs associated with construction. Inclusive capital costs are given for each capital cost estimation curve on a treatment by treatment basis. Noninclusive costs must be estimated by the planner or appraiser.

The term nondepreciating capital costs refers to costs invested in facilities which do not depreciate over the life of the project or project facility under study. Examples are costs of purchased land and working capital. Normally, these costs are not amortized since the value is expected to be the same at the end of the amortization period.

Interest during construction is computed on the basis that the owner will borrow money as needed to finance construction, and will pay simple interest on this money after it is expended. The computation of this cost also may be simplified by assuming a constant rate of expenditure of funds over the construction time required for the process selected. For instance, if the process selected requires 3 years for construction and the cost of money to the owner is 6 percent per year, the interest during construction would amount to 3/2 (averaging expenditure of funds) x 6 percent (interest rate) or 9 percent of the construction cost.

Construction time is highly variable and dependent on the local situation. Construction time refers to the period of time for material suppliers to manufacture, fabricate, and deliver component parts; and the construction forces to prepare facilities and erect and install these component parts.

Startup costs are the costs incurred by the owner during the period immediately after construction and before the plant produces revenue. This period involves tests, training, and establishing operating criteria and norms. The time required during startup may be assumed to be about 1 month, and the cost is about one-twelfth of 1 year's annual costs. This figure can be adjusted.

Owner's General Expenses include indirect costs such as project investigation and studies, construction contract administration, and general overhead and administration costs including consultant fees, etc.

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These costs will vary considerably in accordance with the owner's method of accounting. If no specific information is available, the following can be used as a guide.

Subtotal of Construction Capital Cost	Percentage for Owners General Expense
$ 100,000	15
1,000,000	12
10,000,000	9
100,000,000	7

Working Capital is the ready cash on hand to cover day to day expenses in operating the facilities. These expenses include salaries, chemicals, energy, and maintenance materials. Working capital generally should amount to two months worth of annual costs or 1/6 of total annual operating costs.

Annual costs are obtained from the cost estimating curves. Some additional computations may be necessary.

Unit water costs are determined on a cents per cubic meter basis. In order to do this, capital and operating costs must be reduced to an annual basis. Capital costs are usually amortized over the expected life of the project. The table below gives the percentages of the total capital cost that must be payed each year.

INTEREST RATE

years	5%	6%	7%	8%	10%	12%
20	.0802	.0871	.0944	0.1019	.1175	.1339
25	.0709	.0782	.0859	0.0937	.1102	.1275
30	.0651	.0727	.0806	0.0888	.1061	.1241
40	.0582	.0665	.0750	0.0863	.1023	.1213
50	.0548	.0634	.0725	0.0817	.1009	.1204

Capital Recovery Factor Percentages indicate annual payments which must be made at annually compounded interest rates for terms shown. Use expected interest rate in cost calculations. Term of loan or bond is expected life of equipment or plant.

These factors are applied to depreciating capital costs. Non-depreciating capital costs are paid at simple interest rates. Once annualized capital and operating costs are obtained, they can be divided by the annual water production to obtain unit water costs.

The following example problems illustrate the use of the report.

EXAMPLE 1

A small community, Badwater, currently receives water for its municipal distribution system from a well field. The only treatment it receives is chlorination. The community wishes to build a treatment plant which will produce water that meets the proposed Federal Drinking Water Standards and Guidelines (1974 revision). Water consumption records and planned growth indicate that a 4,800 m^3/day (1.25 MGD) plant will be required. Several chemical analyses taken over a period of several months of the water supply result in the following typical values.

	mg/l
Total Dissolved Solids	1210
Hardness (as $CaCO_3$)	610
Calcium	100
Magnesium	88
Sodium	170
Iron	3.0
Manganese	0.08
Bicarbonate	350
Sulfate	620
Chloride	190
Nitrate (as Nitrogen)	0.2
Fluoride	0.7
pH	8.3
Color (pale yellow)	25 color units
Temperature	55°F

Special sampling and tests indicate heavy metal, biological, and radiological contamination is negligible. A check of the Federal Drinking Water Standards and Guidelines 1974 Standards shows the following limits for contaminants are exceeded.

Contaminant	Sampling Value	FDWS&G - 1974	% Removal Required
Iron	3.0 mg/l	0.3 mg/l	90
Manganese	0.08	0.05	37.5
Sulfate	620	250	60
Color	25 color units	15 color units	40

The water is "very hard", resulting in scaling of piping, plumbing fixtures, and low cleaning efficacy. The pale yellow color is the result of the iron content, and preliminary laboratory tests show that the iron is in an inorganic form, and that removal of the iron will remove the color in the water. In addition to the meeting of Federal

Drinking Water Standards and Guidelines (1974 revision) standards , it is desired that the product water have a TDS level no greater than 500 mg/1.

It is estimated that financing and construction will begin about June 1975. The cost indices obtained for this date are (or are estimated as):

Engineering News Record BCI	1250
Handy-Whitman Index	400
BLS-Labor Cost Index	4.6

SOLUTION:

I. Preliminary Process Determination

The first step is to determine the treatment processes that will be necessary to produce the quality of water desired. The following information is derived from Table VII-1.

Contaminant	Treatment								
	Aeration	Coagulation & Sedimentation or Filtration	Activated Carbon	Chlorination	Ozonation	Reverse Osmosis	Electrodialysis	Ion Exchange	Distillation
Iron & Manganese	90%	-	-	-	-	90-97	80%	-	99.9
Sulfate	-	-	-	-	-	90-97	80%	97%	99
Color	-	95%	100%	90%	100%	MW 200	-	-	-

The following points can be deducted or are known:

1. The four desalinization processes (reverse osmosis, electrodialysis, ion exchange, and distillation) will effectively remove chloride, nitrate, and fluoride ions. (Table VII-1).
2. Although the other inorganic salts are not listed in the tables, the desalinization processes will effectively reduce their levels.

3. Points 1 and 2 mean that the use of these desalinization processes would result in a water of satisfactory TDS and hardness content.

4. Since the laboratory tests indicate that removal of the iron and manganese will also remove the color, aeration will solve both problems, although this is not normally true.

5. Those treatments listed for color removal will not remove iron. This point coupled with point 4 indicates that they would not be effective in this case.

6. Reverse Osmosis and distillation will remove 90% or more of the iron and manganese as well as all other contaminants of interest, and they will produce a product water of satisfactory quality without the use of any other major processes.

7. Electrodialysis will remove only 80% of the iron. Since 90% iron removal is required some pretreatment will be necessary.

8. Ion exchange will not remove iron and pretreatment is necessary.

9. Aeration will precipitate the iron and manganese since they are in inorganic form (Section II). A subsequent treatment such as filtration will be necessary to remove the precipitate.

Collecting the information from the preceding points, the following treatments or combination of treatments are judged to be feasible on a preliminary basis.

A. Aeration + Filtration + Electrodialysis

B. Aeration + Filtration + Ion Exchange

C. Reverse Osmosis

D. Distillation

II. Order of Value Cost Estimate

A rough or approximate cost estimate is now made for each of the predetermined treatments. This is done by selecting the most significant cost from Section IV for each process. This will eliminate from consideration those processes that will obviously not be economically effective. Those which appear to be competitive must be analyzed in more detail. The cost obtained for the second cheapest system can be used as an upper limit for the cheapest system. If this upper limit is exceeded in the cost calculations for the cheapest system then more detailed calculations should be made for the next least expensive system. It must be kept in mind that special conditions (such as availability of cheap power, steam, etc.) may exist in a particular case and the planner may select the second least expensive system over the cheapest for this reason, provided the cost differential is relatively small.

The preliminary cost calculations can also be used to eliminate some treatments or indicate some further modification to the treatment process that may be necessary. This will occur when it is indicated from the cost curves or other calculations that certain limits in the parameters of operations will be approached or exceeded, e.g., unusual temperature, pH, particle size.

The most significant costs associated with each of treatments in the previous section are now determined.

A. Aeration - the most significant cost for aeration is for equipment construction. From Fig. A-1, Aeration Equipment and Construction for a 4,800 m^3/day plant is $11,000.

B. Diatomaceous Earth Filters - Construction Cost for a 4,800 m^3/day plant is $120,000 (Fig. DF-1).

C. Electrodialysis - the most significant cost will be for construction; however, some preliminary calculations must be made.

$$\% \text{ TDS} = \frac{\text{Na} + \text{K} + \text{Cl}}{\text{TDS}_i}$$

where,

TDS = mg/l TDS_i of feed-water = 1210 mg/l
Na = mg/l sodium of feed-water 170 mg/l
K = mg/l potassium of feed-water 0 mg/l
Cl = mg/l chloride of feed-water 190 mg/l

$$\% \text{ TDS} = \frac{170 + 0 + 190}{1210} = \frac{360}{1210} = 0.30 = 30\%$$

The water temperature is 55°F = 13°C

From Fig. ED-1 we obtain by interpolating between the 20% and 40% lines,

Rating Factor = 0.45

Using this rating factor in Fig. ED-2, the fraction of solids remaining per stage is determined to be 0.69 with a stack flow rate of 545 m^3/day. It is important to note that such a system would be relatively inefficient with a low stack flow rate and that the operational limits for the electrodialysis process are closely approached. The number of stages required can be determined by multiplying the fraction of solids remaining by the TDS content until the TDS content remaining is within acceptable limits.

0.69 x 1210 mg/l = 835 mg/l remaining
0.69 x 835 mg/l = 576 mg/l remaining
0.69 x 576 mg/l = 398 mg/l remaining

Since three iterative multiplications are necessary to reduce the TDS level remaining below acceptable limits, the number of stages required is 3. The number of stages required is checked by the calculation.

$$\text{FSR} = \sqrt[n-1]{\frac{\text{TDS}_p}{\text{TDS}_i}} = \sqrt{\frac{398}{1210}} = \sqrt{0.3289} = .573$$

With FSR = .573 and the rating factor = 0.45, the stack flow rate will be less than 545 m^3/day, and 3 stages are sufficient.

The number of stacks required is:

$$\frac{\text{Plant Capacity}}{\text{Stack Capacity}} = \frac{4,800\ m^3/day}{545\ m^3/day/stack} = 8.8 = 9 \text{ stacks}$$

$$9\ \frac{\text{stacks}}{\text{stage}} \times 3 \text{ stages} = 27 \text{ stacks total}$$

From Figure ED-3, Construction costs = $1.25 million.

(D) Ion Exchange

While ion selective resins are available, it will be assumed for initial calculations that the ion exchange process will reduce the level of all inorganic contaminants proportionally, i.e., if the TDS or any contaminant level is lowered by a given percentage, then the remaining contaminants will be reduced proportionally. Neglecting iron and manganese which will be removed in pretreatment, the constituent that must be lowered the greatest percentage in this particular case is sulfate - SO_4 (60%). A 60% reduction in the TDS content produces the following:

1210 mg/l -.60 (1210) mg/l = 484 mg/l, or
1210 - 484 = 726 mg/l reduction

The most significant cost for ion exchange is the plant construction cost. Using a 726 mg/l reduction in TDS for a 4,800 m^3/day plant, it is determined that the plant construction costs will be $530,000. (Fig. IX-1).

(E) Reverse Osmosis

The most significant cost associated with reverse osmosis is the plant construction cost. From Fig. RO-3, this cost is $800,000.

(F) Distillation

From Fig. D-3, the construction costs for distillation plants and steam generation are $3,500,000. Distillation is normally utilized when salt concentrations are very high.

Summarizing the analysis to this point, four potential treatment systems have been selected

System A = Aeration + Filtration + Electrodialysis
System B = Aeration + Filtration + Ion Exchange
System C = Reverse Osmosis
System D = Distillation.

The most significant costs associated with these systems by respective process are:

System A = \$11,000 + \$120,000 + \$1,250,000 = \$1,381,000
System B = \$11,000 + \$120,000 + \$ 530,000 = \$ 661,000
System C = + \$ 800,000 = \$ 800,000
System D = + \$3,500,000 = \$3,500,000.

Ion exchange with pretreatment and reverse osmosis seems to be economically competitive and will require more detailed study. Electrodialysis and distillation will obviously cost much more, and will also have some associated technical difficulties.

Distillation can be dropped from further consideration because of the large cost differential between it and systems B and C. In the case of electrodialysis, it is important to note that the process has adjustable operating parameters. The rating factor, and thus the efficiency, improves with higher feed-water temperature (see Fig. ED-1). If the feed-water, for example, is preheated to 40°C (104°F), the rating factor increases from 0.45 to 1.25. A stack flow rate of 954 m^3/day is possible with this new rating factor. This could eliminate the need for a stage of stacks or reduce the number of stacks per stage and lower the electrodialysis plant costs to a competitive value. However, the cost of heating the water may offset the potential savings, and further study is required to determine whether such system adjustments are worthwhile. In this case, it is assumed that electrodialysis is dropped from further consideration and that more detailed costs will be derived for ion exchange and reverse osmosis.

CAPITAL COST SHEET

PROJECT:

PROJECT DESCRIPTION:

Reverse Osmosis for Badwater

DATE: December 1974

PRICE LEVEL: June 1975

PLANT CAPACITY: 4,800 m^3/day

ANNUAL PRODUCTION: 1,752,000 m^3

INTEREST RATE: 7%

PLANT LIFE: 30 yr.

WATER SUPPLY CHARACTERISTICS:

Iron, manganese, color, and sulfate ion above (Federal Drinking Water Standards and Guidelines - 1974 revision). The water also has a high level TDS and hardness content.

PRODUCT WATER CHARACTERISTICS:

TDS = 500 ppm. All contaminant levels reduced below (Federal Drinking Water Standards and Guidelines - 1974 revision).

A. CAPITAL COST CENTERS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
1. RO Site Development Cost (Fig. RO-2)	$140,000	1250/1154	$ 152,000
2. RO Plant Construction Cost (Fig. RO-3)			
3. (corrected for temperature)	$850,000	400/290.4	$1,171,000
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			

B. SUBTOTAL	$1,323,000
C. INTEREST DURING CONSTRUCTION (say 8 mo. at 7%) = 4.7%	$ 62,000
D. START-UP COSTS (1/12 of Annual Costs)	$ 14,000
E. OWNERS GENERAL EXPENSE (say 12% of subtotal)	$ 158,800
F. TOTAL DEPRECIATING CAPITAL (sum B, C, D, E)	$1,557,800
G. LAND COSTS	$ 500
H. WORKING CAPITAL (1/6 of Annual Operating Costs - Item L)	$ 28,100
I. TOTAL NON-DEPRECIATING COSTS	$ 28,600
J. TOTAL CAPITAL COSTS	$1,586,400

ANNUAL COST SHEET

PROJECT:

DATE: December 1974

PROJECT DESCRIPTION:

Reverse Osmosis for Badwater

K. ANNUAL OPERATING COSTS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
O&M LABOR, SUPPLIES & MAINTENANCE MATERIAL			
12. RO O&M Labor Costs (Fig. RO-4)	$32,000	4.6/4.18	$ 35,200
13. RO O&M Supplies (1% of construction			
14. cost) Item A-2	$11,700	-	$ 11,700
15.			
16.			
17.			
18.			
19.			
20.			
FUEL			
21.			
22.			
23.			
24.			
STEAM			
25.			
26.			
ELECTRIC POWER			
27. RO Power Requirement	$46,250	-	$46,250
28.			
29.			
30.			
CHEMICALS			
31. RO Chemicals	$24,000	-	$ 24,000
32.			
33.			
34.			
35.			
ANNUAL REPLACEMENT COSTS			
36. RO Membrane Replacement	$51,500	-	$ 51,500
37.			
38.			
OTHER ANNUAL COSTS			
39.			
40.			
41.			

L. TOTAL ANNUAL COSTS..	$168,650
M. DEPRECIATING CAPITAL COST (ANNUAL BASIS) 0.0806 x $1,557,800........	$125,600
N. NON-DEPRECIATING CAPITAL (ANNUAL BASIS) .07 x 28,600	$ 2,000
O. TOTAL ANNUAL CAPITAL CHARGES	$127,600
P. TOTAL ANNUAL COSTS (Sum Items L, O).............................	$296,250
Q. COST OF WATER ($ /m^3) $296,250 ÷ [4,800 m^3/day x 365 day/yr.]	17 ¢/m^3

COMPUTATION SHEET

PROJECT:

PROJECT DESCRIPTION:

Reverse Osmosis for Badwater

ANNUAL FUEL COSTS:

Brine to product ratio = BPR

$$BPR = \frac{1-\frac{TDS_p}{TDS_i}}{\frac{900}{Ca_i}-1} = \frac{1-\frac{500}{1210}}{\frac{900}{100}-1} = \frac{1-.413}{9-1} = .07$$

however .11 is min. (see RO section)

Volume brine $V_b = V_p \times BPR$

$V_b = 4{,}800\ m^3/day \times 0.11$

$V_b = 528$ say $530\ m^3/day$

$V_i = V_b + V_p$

$V_i = 4{,}800 + 530 = 5{,}330\ m^3/day$

ANNUAL STEAM COSTS:

ANNUAL POWER COSTS:

Local commercial rate 1.0¢/kwhr.

2,640 kwhr/1000 m^3 (From R.O. Section)

2,640 kwhr/1000 m^3 x 4,800 m^3/day x 365 day/yr. = 4,625,000 kwhr/yr.
4,625,000 kw/yr. x 1.0¢/kwhr. = $46,250/yr.

ANNUAL REPLACEMENT COSTS:

Membrane Replacement $26.40/1000 m^3 at 25°C

Corrected to 13°C $\quad \$26.40/1000\ m^3 \times \frac{5{,}342}{4{,}800} = \$29.38/1000\ m^3$ (see OTHER COMPUTATIONS below)

$29.38/1000 m^3 x 4,800 m^3/day x 365 days/yr. = $51,500/yr.

ANNUAL CHEMICAL COSTS

Chemical Cost $13/1000 m^3

BLS Chemical Index (Sept. 73) = 104.3
BLS Chemical Index (Jun. 75) = 110.0 (assumed)

$\$13/1000\ m^3 \times \frac{110}{104.4} = \$13.70/1000\ m^3 \times 4{,}800\ m^3/day \times 365\ days/yr. = \$24{,}000/yr.$

LAND REQUIREMENTS:

For R.O. - From Fig. RO-1 - 0.1 hectare. Assume land cost $500/hectare.

OTHER COMPUTATIONS:

Plant Capacity Correction - to enter Fig. RO-3.

$$PC = 4{,}800 \times \frac{100 + \left[\frac{5}{9}(25-13) \times 1.7\right]}{100} = \frac{4{,}800 \times [100 + 11.3]}{100} = 5{,}342\ m^3/day$$

CAPITAL COST SHEET

PROJECT:

PROJECT DESCRIPTION:

Aeration + Diatomaceous Filtration
+ Ion Exchange for Town of Badwater.

DATE: December 1974

PRICE LEVEL: June 1975

PLANT CAPACITY: 4,800 m^3/day

ANNUAL PRODUCTION: 1,752,000 m^3

INTEREST RATE: 7%

PLANT LIFE: 30 yr.

WATER SUPPLY CHARACTERISTICS:

Iron, manganese, color, and sulfate ion above Federal Drinking Water Standards and Guidelines - 1974 revision . The water also has high level TDS and hardness content.

PRODUCT WATER CHARACTERISTICS:

TDS = 500 ppm. All contaminant levels reduced below Federal Drinking Water Standards and Guidelines - 1974 revision. Assume that all pretreatment processes, even if non-desalting process, will have 30 year life or the same as the major component.

A. CAPITAL COST CENTERS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
1. IX Plant Construction Cost (Fig. IX-1)	$540,000	400/290.4	$ 744,000
2. IX Site Development (Fig. IX-3)	$140,000	1250/1154	$ 152,000
3. Aeration Equipment Construction			
4. (Fig. A-1) note: 8,300 m^3/day unit	$ 15,000	1250/1154	$ 16,000
5. Diatomaceous Earth Filter Construction			
6. (Fig. DF-1) note: 8,300 m^3/day unit	$200,000	400/290.4	$ 275,000
7.			
8.			
9.			
10.			
11.			

B. SUBTOTAL..	$1,187,000
C. INTEREST DURING CONSTRUCTION(say 8 mo. at 7%) = 4.7%	$ 56,000
D. START-UP COSTS (1/12 of Annual Costs - Item L)	$ 12,600
E. OWNERS GENERAL EXPENSE (say 12% of subtotal)	$ 142,400
F. TOTAL DEPRECIATING CAPITAL (sum B, C, D, E)	$1,398,000
G. LAND COSTS	$ 500
H. WORKING CAPITAL (1/6 of Annual Costs - Item L)	$ 25,000
I. TOTAL NON-DEPRECIATING COSTS (sum G, H)	$ 25,500
J. TOTAL CAPITAL COSTS (sum F, I)	$1,423,500

ANNUAL COST SHEET

PROJECT:
DATE: December 1974

PROJECT DESCRIPTION:
Aeration + Diatomaceous Earth Filtration + Ion Exchange for Badwater

K. ANNUAL OPERATING COSTS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
O&M LABOR, SUPPLIES & MAINTENANCE MATERIAL			
12. IX O&M Labor (Fig. IX-5)	$33,000	4.6/4.18	$ 36,300
13. IX O&M Supplies (1% of construction)			
14. Item A-1	$ 7,400	-	$ 7,400
15. Aeration O&M (Fig. A-2); 8,300 m^3/day			
16. unit	$10,000	4.6/4.18	$ 11,000
17. Diatomite Filter O&M (Fig. DF-3);			
18. 8,300 m^3/day unit	$ 9,400	4.6/4.18	$ 10,300
19. Diatomite Filter O&M Supplies -			
20. (2% of construction) Item A-5	$ 5,500	-	$ 5,500
FUEL			
21.			
22.			
23.			
24.			
STEAM			
25.			
26.			
ELECTRIC POWER			
27. IX Power	$ 4,500	-	$ 4,500
28. Diatomite Filtration Power	$ 3,600	-	$ 3,600
29.			
30.			
CHEMICALS			
31. IX Chemicals	$39,500	-	$ 39,500
32.			
33.			
34.			
35.			
ANNUAL REPLACEMENT COSTS			
36. IX Resin (3% of construction) Item A-1	$22,300	-	$ 22,300
37. Diatomaceous Earth (Fig. D-5)	$10,000	-	$ 10,000
38.			
OTHER ANNUAL COSTS			
39.			
40.			
41.			

L. TOTAL ANNUAL COSTS..	$150,400
M. DEPRECIATING CAPITAL COST (ANNUAL BASIS) (0.0806 x $1,398,000).....	$112,700
N. NON-DEPRECIATING CAPITAL (ANNUAL BASIS) (.07 x 25,500)	$ 1,800
O. TOTAL ANNUAL CAPITAL CHARGES	$114,500
P. TOTAL ANNUAL COSTS (Sum Items L, O)	$264,900
Q. COST OF WATER ($ /m^3) $264,900 ÷ [4,800 m^3/day x 365 day/yr.]	15¢/m^3

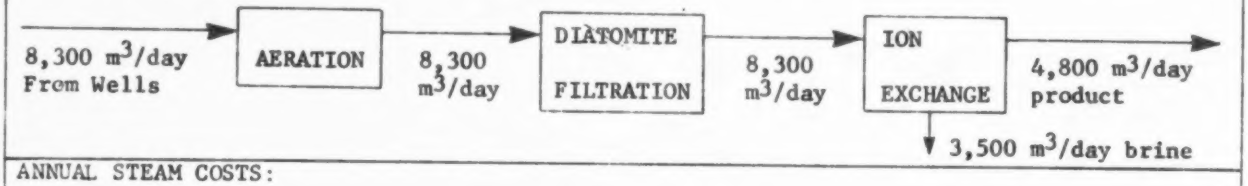
COMPUTATION SHEET

PROJECT:

PROJECT DESCRIPTION:

Aeration = Diatomaceous Filtration + Ion Exchange for Town of Badwater

ANNUAL FUEL COSTS: None


8,300 m^3/day From Wells
AERATION
8,300 m^3/day
DIATOMITE FILTRATION
8,300 m^3/day
ION EXCHANGE
4,800 m^3/day product
3,500 m^3/day brine

ANNUAL STEAM COSTS:

ANNUAL POWER COSTS: From local utility: Commercial rate = 1¢/kwhr.

for IX - 1.25 x 1000 kwhr/day (Fig. IX-6) x 30 day/mo. = 37,500 kwhr/mo.
37,500 kwhr/mo. x 1¢/kwhr/= $375/mo. x 12 mo/yr. = $4,500/yr.

for Diatomite Filtration - 1000 kwhr/day (Fig. DF-4) x 30 day/mo. = 30,000 kwhr/mo.
30,000 kwhr/mo. x 1¢/kwhr/ x 12 mo/hr. = $3,600/yr.

ANNUAL REPLACEMENT COSTS:

Diatomaceous Earth requirement (from Fig. DF-5) = 275 kg/day

275 kg/day x 365 days/yr. = 100,375 kg/yr. say 100,000 kg/yr.

100,000 kg/yr. x 10¢/kg = $10,000/yr.

ANNUAL CHEMICAL COSTS

Say 3¢/m^3 (Fig. IX-4); 3¢/m^3 x 4,800 m^3/day x 365 days/yr. = $52,600/yr.

This is for sulfuric acid at $40/ton (U.S.) Assume available locally at $30/ton.

$$\$52{,}600/\text{yr.} \times \frac{30}{40} = \$39{,}500/\text{yr.}$$

LAND REQUIREMENTS: Area available at $500/hectare

0.1 hectare for IX (Fig. IX-2). Aeration - negligible

0.1 hectare for Diatomite Filtration (Fig. DF-2).

OTHER COMPUTATIONS:

$$BPR = \frac{TDS_i - TDS_p}{1000} = \frac{1210 - 484}{1000} = \frac{726}{1000} = .726$$

$$V_b = V_p \times BPR = 4{,}800\ m^3/\text{day} \times .726 = 3{,}485 \text{ say } 3{,}500\ m^3/\text{day}$$

$$V_i = V_p + V_b = 4{,}800\ m^3/\text{day} + 3{,}500\ m^3/\text{day} = 8{,}300\ m^3/\text{day}.$$

EXAMPLE 2

A large community, Industrytown, has a winter water demand of 25,000 m^3/day and 35,000 m^3/day during the summer. The present city water treatment system consists of coagulation, sedimentation, filtration, and chlorination processes. The treated water supply meets all Federal standards except for Barium (standard level 1.0 mg/l). Analyses of the treated and raw water supplies indicate barium levels of 1.2 mg/l and apparent ineffectiveness of the present treatment system in removing Barium.

Other pertinent information required is:

Engineering News Record BCI	1200*
Handy-Whitman Index	350*
BLS - Labor Cost Index	4.8*
Water Temperature	58°F = 14.4°C
TDS	400ppm
K	250ppm
Cl	75ppm
Na	75ppm
Ca	25ppm

SOLUTION:

I. Preliminary Process Selection

From Table VII-1, it is determined that four processes effectively remove barium.

Treatment	Percentage Removal
Reverse Osmosis	90
Electrodialysis	80
Distillation	99
Ion Exchange	95

Required removal is: 1.2 mg/l - 1.0 mg/l = .2 mg/l

$$\text{or: } \frac{.2 \text{ mg/l}}{1.2 \text{ mg/l}} = 16.7\%$$

---

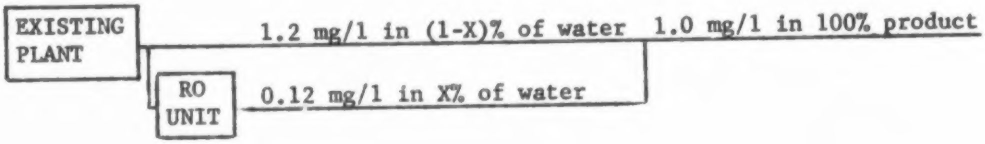
* Assumed for May 1, 1975. Actual values should be obtained from appropriate sources.

Since the removal requirement is only a small portion of the total capability of the process, blending is a distinct possibility. Rather than treat all the raw water, only a portion necessary to bring the barium down to acceptable levels may be treated. A smaller system requirement and concomitant reduction in costs may be realized.

The size of the treatment processes if blending is used can be determined as follows:

> Determine the concentration of the contaminant of interest in the product water for each process.
>
> RO 1.2 mg/l x .90 = 1.08 mg/l removal = .12 mg/l product
> ED 1.2 mg/l x .80 = 0.96 mg/l removal = .24 mg/l product
> Dis 1.2 mg/l x .99 = 1.188 mg/l removal = .012 mg/l product
> IX 1.2 mg/l x .95 = 1.14 mg/l removal = .06 mg/l product

The schematic diagram below illustrates the situation.



On a percentage basis, the following equation is applicable.

> (Concentration RO water) (Proportion of RO water) + (Concentration of existing water) (Proportion of existing water) = (Concentration of Product water) (1 or 100%)

$$\begin{aligned} 0.12\ (X) + 1.2\ (1-X) &= 1.0\ (1) \\ 0.12X + 1.2 - 1.2X &= 1 \\ 1.08X &= .2 \\ X &= .185 \text{ or } 18.5\% \text{ of the water must pass through the RO unit.} \end{aligned}$$

$$35{,}000 \text{ m}^3\text{/day X } .185 = 6{,}475 \text{ m}^3\text{/day} \approx 6{,}500 \text{ m}^3\text{/day}$$

Check calculation is

$$\begin{aligned} 0.12\ (6{,}475) + 1.2\ (28{,}525) &= 1.0\ (35{,}000) \\ 777 + 34.230 &= 35{,}000 \\ 35{,}007 &= 35{,}000 \text{ within accuracy of rounding off.} \end{aligned}$$

Similarly, for

ED = 7,300 m^3/day
Dis = 5,900 m^3/day
IX = 6,200 m^3/day

II. Order of Value of Cost Estimate

The most significant or highest cost associated with each of the predetermined processes is now obtained from the appropriate figures in Section IV, thus eliminating those processes which would be exorbitant in cost. The lowest cost process is then subjected to a more detailed cost estimate.

(A) Reverse Osmosis

The most significant cost associated with reverse osmosis is for plant construction. For a 6,500 m^3/day reverse osmosis plant, plant construction costs are $1,000,000 (Fig. RO-3).

(B) Electrodialysis

Following the procedure outlined in the electrodialysis plant cost calculation section, the cost is determined as follows:

$$\% \text{ TDS} = \frac{(\text{Na+K+Cl})}{\text{TDS}} 100 = \frac{(75+25+75)}{400} 100 = \frac{17500}{400} = 44\%$$

For a feed-water temperature of 58°F = 14.4°C , the rating factor = .55 (Fig. ED-1). Entering Fig. ED-2, the fraction of solids remaining after each stage is 0.635 for a stack flow rate of 545 m^3/day.

The blending premise is based on a 0.24 mg/l of barium in the product water. The raw water level is 1.2 mg/l. Thus, the number of stages needed is:

0.635 x 1.2 mg/l = .762 mg/l product 1st stage
0.635 x 0.762 mg/l = .484 mg/l product 2nd stage
0.635 x 0.484 mg/l = .307 mg/l product 3rd stage
0.635 x 0.307 mg/l = .195 mg/l product 4th stage
∴ 4 stages will be required.

The number of parallel stages is:

$$\frac{7,300 \text{ m}^3/\text{day}}{545 \text{ m}^3/\text{stack/day}} = 13.4 \text{ say 14 stacks per stage.}$$

The total number of stacks = 14 stacks/stage x 4 stages = 56 stacks. From Fig. ED-3, the construction cost for a 56 stack electrodialysis plant (most significant) is $2,100,000.

Alternatively, assume the product water from the electrodialysis plant will contain barium at a level of 0.8 mg/l instead of 0.24 mg/l as originally proposed. If the level is 0.8 mg/l, then 50% of the water must be treated in the electrodialysis plant (50% at 0.8 mg/l and 50% untreated at 1.2 mg/l combined will give a 1.0 mg/l product). Performing the same calculations done previously, the following is obtained:

The number of stages is:

0.635 x 1.2 mg/l = 0.762 mg/l product 1st stage
$\therefore$ only 1 stage required.

The number of parallel stages is:

$$\frac{17{,}500\ (50\%\ \text{of}\ 35{,}000)\ m^3/\text{day}}{545\ m^3/\text{stack/day}} = 32.1 \text{ say } 33 \text{ stacks}$$

The total number of stacks = 33 stacks/stage x 1 stage = 33 stacks. From Fig. ED-3, the construction cost is $1,450,000. This is much less than for a 4 stage 56 stack plant.

(C) Distillation

The most significant cost for a 5,900 m^3/day distillation plant is the construction cost, which is $4,000,000 (Fig. D-3).

(D) Ion Exchange

The most significant cost for ion exchange is plant construction costs (Fig. IX-1). The curves are in terms of TDS reduction. Assume ion exchange removes all contaminants proportionally. Then a 95% reduction of barium (1.2 mg/l to 0.06 mg/l) will also reduce the TDS by 95% or 400 mg/l x 0.95 = 380 mg/l or 20 mg/l TDS will remain. No curve is given for a 380 mg/l TDS reduction in Fig. IX-1. The value for a 6,200 m^3/day plant with a 500 mg/l reduction is TDS is $520,000. It can be assumed that the 380 mg/l TDS reduction plant will be directly proportional in cost since ion exchange construction costs are directly related to the TDS reduction. Therefore,

$$\frac{380\ \text{mg/l reduction}}{500\ \text{mg/l reduction}} = \frac{\$\ (x)}{\$520{,}000}$$

or x = $395,000 (approximately)

The same procedure illustrated above for electrodialysis can also be used in the case of ion exchange. Assume that the barium level is reduced from 1.2 mg/l to 0.8 mg/l or a 33% reduction. This means, of course, that the ion exchange unit will be 17,500 m^3/day instead of 6,200 m^3/day. The TDS reduction is 400 mg/l x 0.33 = 133 mg/l. From Fig. IX-1.

$$\frac{133 \text{ mg/l reduction}}{500 \text{ mg/l reduction}} = \frac{\$ (x)}{\$1,100,000} \qquad (17,500 \text{ m}^3\text{/day plant})$$

$$x = \$293,000 \text{ (approximately)}$$

In summary, the order of value costs for each of the processes under consideration is:

Reverse Osmosis	(6,500 m^3/day)	$1,000,000
Electrodialysis	(7,300 m^3/day)	$2,100,000
Electrodialysis	(17,500 m^3/day)	$1,450,000
Distillation	(5,900 m^3/day)	$4,000,000
Ion Exchange	(6,200 m^3/day)	$ 395,000
Ion Exchange	(17,500 m^3/day)	$ 293,000

Obviously, ion exchange is the cheapest process and a more detailed cost estimate should be made.

CAPITAL COST SHEET

PROJECT: Ion Exchange Unit for Industrytown (6,200 m^3/day unit)

PROJECT DESCRIPTION:

Ion exchange unit for Industrytown; (Product water from ion exchange unit has 0.06 mg/l barium level.) Blending will be used. Total water demand is 35,000 m^3/day in summer, 25,000 m^3/day in winter. Assume former for all calculations

DATE: May 1, 1975

PRICE LEVEL: May 1, 1975

PLANT CAPACITY: 6,200 m^3/day

ANNUAL PRODUCTION: 2,263,000 m^3

INTEREST RATE: 8%

PLANT LIFE: 30 yr.

WATER SUPPLY CHARACTERISTICS:

Meets all requirements except for barium standards (1.2 mg/l). Barium standard 1.0 mg/l.

PRODUCT WATER CHARACTERISTICS:

Reduce barium to standard level by blending 6,200 m^3/day of product water at 0.6 mg/l with 28,800 m^3/day from existing plant.

A. CAPITAL COST CENTERS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
1. IX Plant Construction Costs (Fig. IX-1)	$395,000	350/290.4	$476,000
2. IX Site Development Costs (Fig. IX-3)	$107,000	1200/1154	$111,300
3.			
4. (For 6,200 m^3/day plant)			
5.			
6.			
7.			
8.			
9.			
10.			
11.			

B. SUBTOTAL...	$587,300
C. INTEREST DURING CONSTRUCTION (say 8 mo. at 8%) = 5.3%	$ 31,100
D. START-UP COSTS (1/12 of Annual Costs - Item L)	$ 8,450
E. OWNERS GENERAL EXPENSE (say 12% of subtotal)	$ 70,500
F. TOTAL DEPRECIATING CAPITAL (sum B, C, D, E)	$697,350
G. LAND COSTS (negligible; use existing)	$ 0
H. WORKING CAPITAL (1/6 of Annual Costs - Item L)	$ 16,900
I. TOTAL NON-DEPRECIATING COSTS (sum G, H)	$ 16,900
J. TOTAL CAPITAL COSTS	$714,250

ANNUAL COST SHEET

PROJECT:

DATE: May 1, 1975

PROJECT DESCRIPTION:

6,200 m^3/day IX unit for Industrytown

K. ANNUAL OPERATING COSTS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
O&M LABOR, SUPPLIES & MAINTENANCE MATERIAL			
12. IX Operation & Maintenance Labor			
13. (Fig. IX-5)	$37,000	7.18/6.25	$ 42,500
14. IX O&M Supplies (1% of construction			
15. Item A-1)	$ 4,750	-	$ 4,750
16.			
17. (Use data for 35,000 m^3/day)			
18.			
19.			
20.			
FUEL			
21.			
22.			
23.			
24.			
STEAM			
25.			
26.			
ELECTRIC POWER			
27. IX Power Requirement	$ 2,400	-	$ 2,400
28.			
29.			
30.			
CHEMICALS			
31. IX Regenerant Cost	$37,600	-	$ 37,600
32.			
33.			
34.			
35.			
ANNUAL REPLACEMENT COSTS			
36. IX Resin (3% of construction) Item A-1)	$14,300	-	$ 14,300
37.			
38.			
OTHER ANNUAL COSTS			
39.			
40.			
41.			
L. TOTAL ANNUAL COSTS..			$101,550
M. DEPRECIATING CAPITAL COST (ANNUAL BASIS) (.0888 x $714,250)			$ 63,400
N. NON-DEPRECIATING CAPITAL (ANNUAL BASIS) (.08 x 16,900)			$ 1,350
O. TOTAL ANNUAL CAPITAL CHARGES...			$ 64,750
P. TOTAL ANNUAL COSTS (Sum Items L, O)................................			$166,300
Q. COST OF WATER ($ /m^3)..			7.3 ¢/m^3* 1.3 ¢/m3‡

*IX Treated water basis ‡Total product water basis.

COMPUTATION SHEET

PROJECT: 6,200 m^3/day IX unit for Industrytown

PROJECT DESCRIPTION:

Ion exchange unit for Industrytown; Blending will be used. Total water demand is 35,000 m^3/day.

ANNUAL FUEL COSTS:

NOTE: Annual costs given here are for 6,200 m^3/day unit. It can be argued that these costs will be lower if the total water production is 35,000 m^3/day for 6 months and 25,000 m^3/day for 6 months, and thus the IX volume 6,200 m^3/day and 4,400 m^3/day respectively. This can be done if desired. It is preferable, however, to always be too conservative (too high) in costs estimates. The annual costs for a 6,200 m^3/day unit for the full year are therefore used here.

ANNUAL STEAM COSTS:

ANNUAL POWER COSTS:

Electric Power for 6,200 m^3/day unit = 1,650 kwhr/day. From Fig. IX-6.
Cost from local power utility, 4 mils/kwhr = .004¢/kwhr
1,650 kwhr/day x 365 days/yr. x .004$/kwhr = $2,400/yr.

ANNUAL REPLACEMENT COSTS:

ANNUAL CHEMICAL COSTS

IX Regenerant Cost (Fig. IX-4) for 380 mg/l reduction in TDS, say 1.75¢/m^3
1.75¢/m^3x6,200m^3/dayx365 days/yr. = $39,600.
Sulfuric Acid available at $38/ton (U. S.) $39{,}600 \times \frac{\$38}{\$40} = \$37{,}600$

LAND REQUIREMENTS:

For 6,200 m^3/day ion exchange unit; negligible land requirements. Say 0.1 hectare (Fig. IX-2). Assume available at existing treatment site.

OTHER COMPUTATIONS:

Update of BLS Labor Index

$$\frac{4.8 \text{ (Index May '75)}}{4.18 \text{ (Report Index)}} = \frac{(X) \text{ (Updated Modified Index)}}{6.25 \text{ (Report Index Modified to include overhead, etc.)}}$$

X = 7.18

CAPITAL COST SHEET

PROJECT: Ion Exchange Unit for Industrytown (17,500 m^3/day unit)

PROJECT DESCRIPTION:

Ion exchange unit for Industrytown. Product water will have 0.8 mg/1 barium level. Blending will be used. Total water demand is 35,000 m^3/day.

DATE: May 1, 1975
PRICE LEVEL: May 1, 1975
PLANT CAPACITY: 17,500 m^3/day
ANNUAL PRODUCTION: 6,387,500 m^3
INTEREST RATE: 8%
PLANT LIFE: 30 yr.

WATER SUPPLY CHARACTERISTICS:

Meets all requirements except for barium standards (1.2 mg/1).
Barium standard 1.0 mg/1.

PRODUCT WATER CHARACTERISTICS:

Reduce barium to standard level by blending 17,500 m^3/day of product water at 0.8 mg/1 with 17,500 m^3/day from existing plant.

A. CAPITAL COST CENTERS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
1. IX Plant Construction Costs (Fig. IX-1)	$293,000	350/290.4	$353,000
2. IX Site Development Costs (Fig. IX-3)	$333,000	1200/1154	$346,300
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			

B. SUBTOTAL	$699,300
C. INTEREST DURING CONSTRUCTION (say 8 mo. at 8%) = 5.3% of Item B	$ 37,100
D. START-UP COSTS (1/12 of Annual Costs - Item L)	$ 9,900
E. OWNERS GENERAL EXPENSE (say 12% of subtotal)	$ 83,900
F. TOTAL DEPRECIATING CAPITAL (sum B, C, D, E)	$830,200
G. LAND COSTS (negligible - use existing)	$ -
H. WORKING CAPITAL (1/6 of Annual Costs - Item L)	$ 19,800
I. TOTAL NON-DEPRECIATING COSTS (sum G, H)	$ 19,800
J. TOTAL CAPITAL COSTS (sum F, I)	$850,000

ANNUAL COST SHEET

PROJECT: 17,500 m^3/day IX unit for Industrytown DATE: May 1, 1975

PROJECT DESCRIPTION:

K. ANNUAL OPERATING COSTS:	ESTIMATED COST	COST INDEX	CURRENT ESTIMATED COST
O&M LABOR, SUPPLIES & MAINTENANCE MATERIAL			
12. IX Operation & Maintenance Labor			
13. (Fig. IX-5)	$60,000	7.18/6.25	$ 68,900
14. IX O&M Supplies (1% of construction -			
15. Item A-1)	$ 3,500	-	$ 3,500
16.			
17.			
18.			
19.			
20.			
FUEL			
21.			
22.			
23.			
24.			
STEAM			
25.			
26.			
ELECTRIC POWER			
27. IX Power Requirement	$ 5,500	-	$ 5,500
28.			
29.			
30.			
CHEMICALS			
31. IX Regenerant Cost	$30,300	-	$ 30,300
32.			
33.			
34.			
35.			
ANNUAL REPLACEMENT COSTS			
36. IX Resin (3% of construction -			
37. Item A-1)	$10,600	-	$ 10,600
38.			
OTHER ANNUAL COSTS			
39.			
40.			
41.			

L. TOTAL ANNUAL COSTS..	$118,800
M. DEPRECIATING CAPITAL COST (ANNUAL BASIS) (0.08888 x $850,000)	$ 75,500
N. NON-DEPRECIATING CAPITAL (ANNUAL BASIS) (0.08 x $19,800)	$ 1,600
O. TOTAL ANNUAL CAPITAL CHARGES	$ 77,100
P. TOTAL ANNUAL COSTS (Sum Items L, O)	$195,900
Q. COST OF WATER ($ /m^3)........................ Treated water basis	3.0 ¢/m^3
Total product water basis	1.5 ¢/m^3

COMPUTATION SHEET

PROJECT: 17,500 m^3/day IX unit for Industrytown

PROJECT DESCRIPTION:

ANNUAL FUEL COSTS:

-

ANNUAL STEAM COSTS:

-

ANNUAL POWER COSTS:

Electric power for 17,500 m^3/day unit = 3,800 kwhr/day (From Fig. IX-6)

Cost from local power utility, 4 mils/kwhr.

3,800 kwhr/day x 365 day/yr. x .004 \$/hr. = \$5,500/yr.

ANNUAL REPLACEMENT COSTS:

-

ANNUAL CHEMICAL COSTS

IX Regenerant Cost (Fig. IX-4) - For 133 mg/l reduction in TDS, say 0.5 ¢/m^3

0.5 ¢/m^3 x 17,500 m^3/day x 365 days/yr. = \$31,900

Corrected for Sulfuric Acid available at \$38/ton (U.S.) \$31,900 x $\frac{38}{40}$ = \$30,300

LAND REQUIREMENTS:

For 17,500 m^3/day - 0.5 hectare (Fig. IX-2). Assume available.

OTHER COMPUTATIONS:

-

EXAMPLE 3

A small community, Flyspeck, currently has an average daily water consumption of 800 m^3/day. The water is supplied to the town untreated. Sampling indicates that the water meets all drinking water standards except for high bacteriological levels, specifically high coliform counts. The bacteria are not attached to suspended matter. The town council has decided that some form of treatment must be provided and that the treatment equipment to process must have a capacity of 1,200 m^3/day to allow for possible future town development. The town council would like to know what alternatives are available and what the costs will be on a preliminary basis. Tests reveal that a 50% reduction in bacteria level is necessary to meet Standards. The treatment facility would be built in July 1976. An estimate of the indexes, based on recent trends, for July 1976 are:

Engineering News Record Building Cost Index .... = 1380

Handy-Whitman Index .... = 350

Labor Cost Index .... = 4.6

SOLUTION:

From Table VII-1, the following processes are effective in the treatment of high bacteria levels.

Process	% Removal of Bacteria
1. Slow Sand Filtration	85-90
2. Diatomaceous Filtration	85-90
3. Microscreening	50
4. Chlorination	99+
5. Ozonation	99+

Some further background information is

PLANT CAPACITY:	1,200 m^3/day
DATE OF ESTIMATE:	November, 1975
PRICE LEVEL DATE:	July, 1976
INTEREST RATE:	7%

Labor Cost Index modification to include overhead and payroll expense.

$$\frac{\text{(BLS Index July 1976 } 4.6}{\text{(BLS Index from report) } 4.18} = \frac{x \text{ (modified BLS Index)}}{6.25 \text{ (modified BLS Index in report)}}$$

$x = 6.88$

(1) SLOW SAND FILTRATION

	Capital Cost Centers	Estimated Cost	Cost Index	Current Estimated Cost
1.	Slow Sand Filtration Constr. (Fig. SF-2)	$120,000	350/290.4	$144,600
2.	Site Development (Fig. SF-3)	$ 11,000	1380/1154	$ 13,100
3.	Subtotal			$157,700
	Annual Operating Costs			
4.	Slow Sand Filtration Labor (Fig. SF-4)	$ 12,000	6.88/6.25	$ 13,200
5.	Slow Sand Filtration O&M (Fig. SF-4)	$ 6,000	6.88/6.25	$ 6,600
6.	Total Annual Operating Costs			$ 19,800
	Total Capital Costs			
7.	Capital Cost Subtotal (from 3)			$157,700
8.	Interest during construction (say 3 months construction time 7% simple interest for 3 months equals 1.75%. This is applied to subtotal)			$ 2,800
9.	Start-up Costs (includes operator training, debugging, etc. Say 1 month applied to total annual operating costs or 1/12 of $19,800)			$ 1,600
10.	Owners General Expense (say 10% of subtotal)			$ 15,800
11.	Total Depreciating Capital Cost (sum items 7, 8, 9, 10)			$177,900
12.	Working Capital (say 1/6 of annual operating costs). This is non-depreciating capital cost.			$ 3,300
13.	Total Capital Cost (sum items 11 and 12)			$181,200

Annual Costs	Estimated Cost	Cost Index	Current Estimated Cost
14. Annual Depreciating Capital Cost (0.075 x 177,900) (Capital Recovery Factor for 7% interest over 40 years; i.e., plant life, is 0.075)			$ 13,340
15. Annual Non-Depreciating Capital Cost (0.07 x $3,300) (7% simple interest over 40 years)			$ 230
16. Total Annual Capital Costs (sum items 14 and 15)			$ 13,570
17. Total Annual Costs (sum items 6, 16)			$ 33,370

(2) DIATOMACEOUS EARTH FILTRATION

	Capital Cost Centers	Estimated Cost	Cost Index	Current Estimated Cost
1.	Diatomaceous Filter Construction Cost (Fig. DF-1)	$ 34,000	350/290.4	$ 41,000
2.	Subtotal			$ 41,000
	Annual Operating Costs			
3.	Diatomaceous Filter Labor & O&M (Fig. DF-3)	$ 1,900	6.88/6.25	$ 2,100
4.	Electric Power (275,000 kwhr/yr. (Fig. DF-4), local rate 1¢/kwhr.	$ 2,750	-	$ 2,750
5.	Diatomaceous Earth (40 kg/day Fig. DF-5) (40 kg/day x 365 day/yr x 12¢/kg)	$ 1,750	-	$ 1,750
6.	Total Annual Operating Costs			$ 6,600
	Total Capital Costs			
7.	Capital Cost Subtotal (From item 2)			$ 41,000
8.	Interest During Construction (3 months construction time. 7% for 3 months = 1.75% applied to subtotal)			$ 700
9.	Start-up Costs (say 1/12 of $6,600)			$ 550
10.	Owner's General Expense (say 10% of subtotal)			$ 4,100
11.	Total Depreciating Capital Cost (sum items 7, 8, 9, 10)			$ 46,350
12.	Working Capital (say 1/6 of annual operating costs)			$ 1,100
13.	Total Capital Cost (sum items 11 and 12)			$ 47,450

Annual Costs	Estimated Cost	Cost Index	Current Estimated Cost
14. Annual Depreciating Capital Cost (0.075 x $47,010) (plant life 40 years)			$ 3,525
15. Annual Non-Depreciating Capital Cost (0.07 x $1,100)			$ 75
16. Total Annual Capital Costs (sum items 14, 15)			$ 3,600
17. Total Annual Costs (sum items 6, 16)			$ 10,200

(3) MICROSCREENING

	Capital Cost Centers	Estimated Cost	Cost Index	Current Estimated Cost
1.	Microscreening Construction Cost (Fig. MS-1)	$ 30,000	350/290.4	$ 36,150
2.	Microscreening Site Development Cost (Fig. MS-2)	$ 9,000	1380/1154	$ 10,750
3.	Subtotal			$ 46,900
	Annual Operating Costs			
4.	Microscreening O&M Labor (Fig. MS-3)	$ 25,000	6.88/6.25	$ 27,500
5.	Microscreening other O&M costs (Fig. MS-3)	$ 5,800	6.88/6.25	$ 6,400
6.	Total Annual Operating Costs			$ 33,900
	Total Capital Costs			
7.	Capital Cost Subtotal (from item 3)			$ 46,900
8.	Interest During Construction (3 months at 7% = 1.75%)			$ 825
9.	Start-up Costs (say 1/12 of $33,900)			$ 2,825
10.	Owner's General Expense (say 10% of subtotal)			$ 4,700
11.	Total Depreciating Capital Cost (sum items 7, 8, 9, 10)			$ 55,250
12.	Working Capital (say 1/6 of annual operating costs)			$ 5,650
13.	Total Capital Cost (sum items 11 and 12)			$ 60,900

Annual Costs	Estimated Cost	Cost Index	Current Estimated Cost
14. Annual Depreciating Capital Cost (0.075 x $61,000) (plant life 40 years)			$ 4,575
15. Annual Non-Depreciating Capital Cost (0.07 x $5,650)			$ 400
16. Total Annual Capital Costs (sum items 14 and 15)			$ 4,975
17. Total Annual Costs (sum items 6, 16)			$ 38,875

(4A) CHLORINATION GAS FEED SYSTEM

	Capital Cost Centers	Estimated Cost	Cost Index	Current Estimated Cost
1.	Gas Chlorination Equipment Cost (Fig. DN-1)	$ 5,800	350/290.4	$ 7,000
2.	Equipment Enclosure Cost (Fig. DN-2)	$ 1,000	1380/1154	$ 1,200
3.	Subtotal			$ 8,200
	Annual Operating Costs			
4.	Chlorine Gas (Typical dosage 1-10 mg/l for bacteria) (Table DN-2). Tests indicate 6.5 mg/l + 0.5 mg/l residual required. Cl_2 in kg/day = plant capacity. (m^3/day x mg/l x 9.98×10^{-4} or = 1,200 m^3/day x 7 mg/l x 9.98×10^{-4} = 8.3 kg/day. Assume cylinder used. 8.3 kg/day x 365 day/yr x $0.27/kg (Table DN-1)	$ 820	-	$ 820
5.	Total Annual Operating Cost			$ 820
	Total Capital Costs			
6.	Capital Cost Subtotal (item 3)			$ 8,200
7.	Interest During Construction (negligible)			$ 0
8.	Start-up Costs (say 1/8 of annual operating cost)			$ 100
9.	Owner's General Expense (say 10% of subtotal)			$ 820
10.	Total Depreciating Capital Cost (sum items 6, 7, 8, 9)			$ 9,120

	Total Capital Costs	Estimated Cost	Cost Index	Current Estimated Cost
11.	Working Capital (negligible)			$ 0
12.	Total Capital Cost (sum items 10 and 11)			$ 9,120
	Annual Costs			
13.	Annual Depreciating Capital Cost (0.381 x $9,120) (plant life 3 yrs. 7% interest paid over 3 years means 0.381 of total must be paid each year.)			$ 3,475
14.	Total Annual Capital Costs (non-depreciating cost negligible)			$ 3,475
15.	Total Annual Costs (sum items 5, 14)			$ 4,295

(4B) CHLORINATION - SODIUM HYPOCHLORITE SYSTEM

	Capital Cost Centers	Estimated Cost	Cost Index	Current Estimated Cost
1.	Hypochlorite Equipment Cost (Fig. DN-3)	$ 4,200	350/290.4	$ 5,050
2.	Equipment Enclosure Cost (Fig. DN-2)	$ 1,000	1380/1154	$ 1,200
3.	Subtotal			$ 6,250
	Annual Operating Costs			
4.	Sodium Hypochlorite 8.3 kg/day (Cl_2) x 365 days/year x $0.425 kg equivalent cost kg Cl_2 in NaClO	$ 1,300	-	$ 1,300
5.	Total Annual Operating Cost			$ 1,300
	Total Capital Costs			
6.	Capital Cost Subtotal (item 3)			$ 6,250
7.	Interest During Construction (negligible)			$ 0
8.	Start-up Costs (say 1/8 of annual operating cost)			$ 160
9.	Owner's General Expense (say 10% of subtotal)			$ 625
10.	Total Capital Cost (sum items 6, 7, 8, 9)			$ 7,035
11.	Working Capital (negligible)			$ 0
12.	Total Capital Cost (sum items 10, 11)			$ 7,035

Annual Costs	Estimated Cost	Cost Index	Current Estimated Cost
13. Annual Depreciating Capital Cost (0.381 x $7,035) (plant life 3 years)			$ 2,680
14. Total Annual Costs (non-depreciating costs negligible)			$ 2,680
15. Total Annual Costs (sum items 5, 14)			$ 3,980

(4C) CHLORINATION - ELECTROLYSIS SYSTEM

	Capital Cost Centers	Estimated Cost	Cost Index	Current Estimated Cost
1.	Electrolysis Equipment Cost (Fig. DN-3)	\$ 5,400	350/290.4	\$ 6,500
2.	Electrolysis Enclosure Cost (Fig. DN-2)	\$ 1,000	1380/1154	\$ 1,200
3.	Subtotal			\$ 7,700
	Annual Operating Costs			
4.	Electrolysis Generator O&M (Fig. DN-4)	\$ 1,400	6.88/6.25	\$ 1,525
5.	Electrolysis Electric Power (6.61 kwhr/kg hypochlorite x $\frac{1\text{kg } Cl_2}{.09\text{ kg hypochlorite}}$ or 73.4 kwhr/kg Cl_2 x 8.3 kg Cl_2/day x 365 day/yr. x 1¢/kwhr =)	\$ 2,225	-	\$ 2,225
6.	Salt $\frac{3\text{ kg salt}}{1\text{ kg hypochlorite}} \times \frac{1\text{kg hypochlorite}}{.09\text{ kg } Cl_2} \times \frac{3¢}{\text{kg salt}} = \$1.00\text{ kg Cl}$ \$1.00 kg Cl x 8.3 kg/day x 365 day/yr =	\$ 3,000	-	\$ 3,000
7.	Total Annual Operating Cost (sum items 4, 5, 6)			\$ 6,750
	Total Capital Costs			
8.	Capital Cost Subtotal (item 3)			\$ 7,700
9.	Interest During Construction (negligible)			\$ 0
10.	Start-up Costs (say 1/8 of annual operating costs)			\$ 850

Total Capital Costs	Estimated Cost	Cost Index	Current Estimated Cost
11. Owner's General Expense (say 10% of subtotal)			$ 675
12. Total Depreciating Capital Cost (sum items 8, 9, 10, 11)			$ 9,225
13. Working Capital (negligible)			$ 0
14. Total Capital Cost (sum items 12 and 13)			$ 9,225
Annual Cost			
15. Annual Depreciating Capital Cost (0.381 x $9,225)			$ 3,500
16. Total Annual Cost (items 7 and 15)			$ 10,250

(5) OZONATION

	Capital Cost Centers	Estimated Cost	Cost Index	Current Estimated Cost
1.	Ozonation System Construction Cost (Fig. DN-5)	\$ 17,500	350/290.4	\$ 21,100
2.	Ozone Generator Enclosure Cost (Fig. DN-7)	\$ 2,000	1350/1154	\$ 2,350
3.	Subtotal			\$ 23,450
	Annual Operating Costs			
4.	Electric Power Costs (Tests indicate 3 mg/l ozone required. Fig. DN-6 for 5 ppm. Calculate as follows: Water density 1 gm/cm^3 = 1,000 kg/m^3 - 1,200 m^3/day x 1,000 kg/m^3 = 1.2 x 10^6 kg/day. $3 \text{ mg/l } O_3 = \frac{3 \text{ kg } O_3}{1 \times 10^6 \text{ kg } H_2O} \times 1.2 \times 10^6 \text{ kg } H_2O\text{/day} = 3.6 \text{ kg } O_3$ 3.6 kgO_3 x 27.5 kwhr/kg = 99 kwhr/day - 99 kwhr/day x 365 day/yr. x 1¢/kwhr.	\$ 360	-	\$ 360
5.	Total Annual Operating Cost			\$ 360
	Total Capital Costs			
6.	Capital Cost Subtotal (item 3)			\$ 23,450
7.	Interest During Construction (1 month at 7% = 0.58%) (1 month for construction - applied to subtotal)			\$ 140
8.	Start-up Costs (say 1/8 of annual operating costs)			\$ 45
9.	Owner's General Expense (say 10% of subtotal)			\$ 2,350

Total Capital Costs	Estimated Cost	Cost Index	Current Estimated Cost
10. Total Depreciating Capital Cost (sum 6, 7, 8, 9)			$ 25,985
11. Total Capital Cost (non-depreciating costs negligible)			$ 25,985
Annual Costs			
12. Annual Depreciating Capital Cost (0.244 x $25,985) (plant life 5 yrs. 7% interest and retirement after 5 yrs. means 0.244 of total must be paid each year.			$ 6,340
13. Total Annual Capital Cost			$ 6,340
14. Total Annual Cost (sum items 5 and 13)			$ 6,700

IN SUMMARY:

	Treatment Process	Effectiveness In Removing Bacteria	Annual Cost	Cost per* Cubic Meter
1.	Slow Sand Filtration	very good	$33,370	7.6¢
2.	Diatomaceous Earth Filtration	very good	$10,200	2.3¢
3.	Microscreening	poor	$38,450	8.8¢
4.	Chlorination			
	a. Gas Feed	excellent	$ 4,295	1.0¢
	b. Sodium Hypochlorite	excellent	$ 3,980	0.9¢
	c. Electrolysis	excellent	$10,250	2.3¢
5.	Ozonation	excellent	$ 6,700	1.5¢

* based on 1,200 m^3/day production.

It appears that chlorination, using either gas feed or sodium hypochlorite, would be both the most effective method of treatment as well as the cheapest. Costs are so close for these two methods that they can be considered equal and other factors, such as chlorine gas or sodium hypochlorite availability, will decide which system is chosen.

APPENDIX A

PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS 1962*

3. BACTERIOLOGICAL QUALITY

3.1 Sampling

3.11 Compliance with the bacteriological requirements of these Standards shall be based on examination of samples collected at representative points throughout the distribution system. The frequency of sampling and the location of sampling points shall be established jointly by the Reporting Agency and the Certifying Authority after investigation by either agency, or both, of the source, method of treatment, and protection of the water concerned.

3.12 The minimum number of samples to be collected from the distribution system and examined each month should be in accordance with the number on the graph in Figure I, for the population served by the system. For the purpose of uniformity and simplicity in application, the number determined from the graph should be in accordance with the following: for a population of 25,000 and under-to the nearest 1; 25,001 to 100,000- to the nearest 5; and over 100,000-to the nearest 10.

3.13 In determining the number of samples examined monthly, the following samples may be included, provided all results are assembled and available for inspection and the laboratory methods and technical competence of the laboratory personnel are approved by the Reporting Agency and the Certifying Authority:

(a) Samples examined by the Reporting Agency.

(b) Samples examined by local government laboratories.

(c) Samples examined by the water works authority.

(d) Samples examined by commercial laboratories.

3.14 The laboratories in which these examinations are made and the methods used in making them shall be subject to inspection at any time by the designated representatives of the Certifying Authority and the Reporting Agency. Compliance with the specified procedures and the results obtained shall be used as a basis for certification of the supply.

3.15 Daily samples collected following a bacteriologically unsatisfactory sample as provided in sections 3.21, 3.22, and 3.23 shall be considered as special samples and shall not be included in the total number of samples examined. Neither shall such special samples be used as a basis for prohibiting the supply, provided that: (1) When waters of unknown quality are being examined, simultaneous tests are made on multiple portions of a geometric series to determine a definitive coliform content; (2) Immediate and active efforts are made to locate the cause of pollution; (3) Immediate action is taken to eliminate the cause; and (4) Samples taken following such remedial action are satisfactory.

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*Bacteria standards for 1974 are the same as the 1962 standards

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3.2 Limits. - The presence of organisms of the coliform group as indicated by samples examined shall not exceed the following limits:

3.21 When 10 ml standard portions are examined, not more than 10 percent in any month shall show the presence of the coliform group. The presence of the coliform group in three or more 10 ml portions of a standard sample shall not be allowable if this occurs:

(a) In two consecutive samples;

(b) In more than one sample per month when less than 20 are examined per month; or

(c) In more than 5 percent of the samples when 20 or more are examined per month.

When organisms of the coliform group occur in 3 or more of the 10 ml portions of a single standard sample, daily samples from the same sampling point shall be collected promptly and examined until the results obtained from at least two consecutive samples show the water to be of satisfactory quality.

3.22 When 100 ml standard portions are examined, not more than 60 percent in any month shall show the presence of the coliform group. The presence of the coliform group in all five of the 100 ml portions of a standard sample shall not be allowable of this occurs:

(a) In two consecutive samples;

(b) In more than one sample per month when less than five are examined per month; or

(c) In more than 20 percent of the samples when five or more are examined per month.

When organisms of the coliform group occur in all five of the 100 ml portions of a single standard sample, daily samples from the same sampling point shall be collected promptly and examined until the results obtained from at least two consecutive samples show the water to be of satisfactory quality.

3.23 When the membrane filter technique is used, the arithmetic mean coliform density of all standard samples examined per month shall not exceed one per 100 ml. Coliform colonies per standard sample shall not exceed 3/50 ml, 4/100 ml, 7/200 ml, or 13/500 ml. in:

(a) Two consecutive samples;

(b) More than one standard sample when less than 20 are examined per month; or

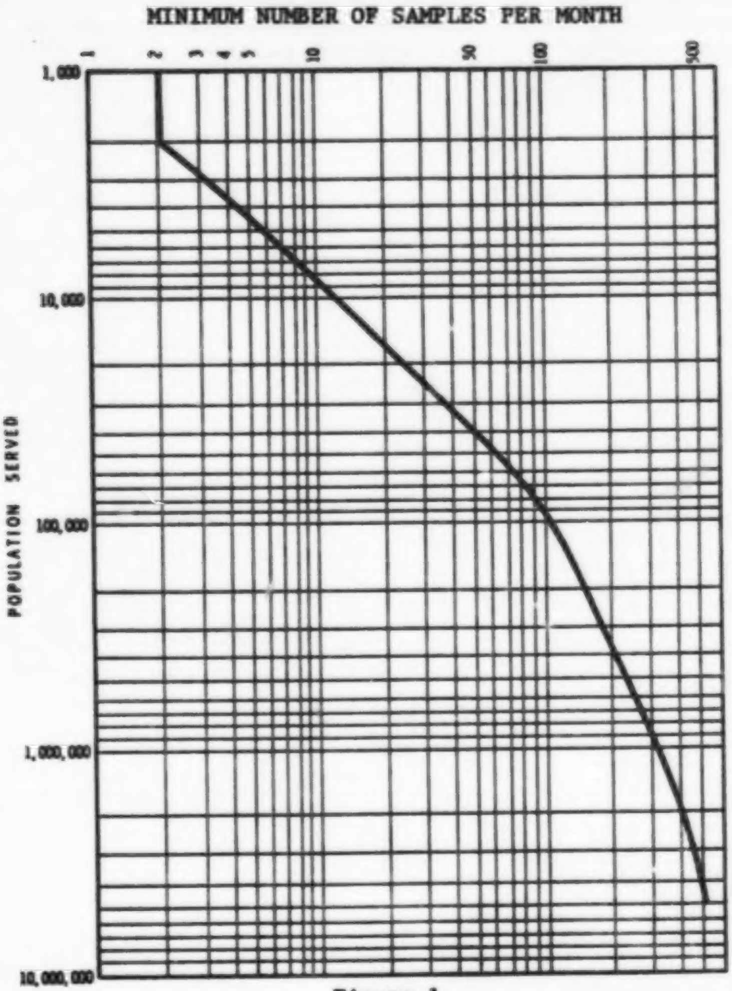

Figure 1

Source: Public Health Service Drinking Water Standards 1962
H.E.W., No. 956, 1962, p.4

(c) More than five percent of the standard samples when 20 or more are examined per month.

When coliform colonies in a single standard sample exceed the above values, daily samples from the same sampling point shall be collected promptly and examined until the results obtained from at least two consecutive samples show the water to be of satisfactory quality.

APPENDIX B

SODIUM

Man's intake of sodium is mostly influenced by the use of salt. Intake of sodium chloride for American males is estimated to be 10 grams per day, with a range of 4 to 24 grams (1). This would be a sodium intake of 1600 to 9600 mg per day. Intake of these amounts is considered by most to have no adverse effect on normal individuals. Even Dahl, who has been one of the strong advocates of the need for restricting salt intake, has felt that an intake of 2000 mg of sodium could be allowed for an adult without a family history of hypertension. Intake of sodium from hospital "house" diets has been measured recently (2). The sodium content of a pool of 21 consecutive meals that were seasoned by the chef or the dietitian from twenty selected general hospitals was determined each quarter. The average sodium intake per capita per day was 3625 ± 971 (SD) milligrams. The intake could be greatly changed between individuals who never add salt to the food at the table and the individuals who always add salt even before tasting.

The taste threshold of sodium in water depends on several factors (3). The predominant anion has an effect; the thresholds for sodium were 500 mg/l from sodium chloride, 700 mg/l from sodium nitrate, and 1000 mg/l from sodium sulfate. A heavy salt user had a threshold of taste that was 50 percent higher, and the taste was less detectable in cold water.

Six of 14 infants exposed to a sodium concentration of 21,140 mg/l died when salt was mistakenly used for sugar in their formula (4). Sea water would have about 10,000 mg/l of sodium.

Severe exacerbation of chronic congestive heart failure due to sodium in water has been documented (3). One patient required hospitalization when he changed his source of domestic water to one that had 4200 mg/l sodium. Another patient was readmitted at two-to-three-week intervals when using a source of drinking water of 3500 mg/l sodium.

Sodium-restricted diets are used to control several disease conditions of man. The rationale, complications, and practical aspects of their use were reviewed by a committee on food and nutrition of National Research Council (5). Sodium-restrictive diets are essential in treating congestive cardiac failure, hypertension, renal disease, cirrhosis of the liver, toxemias of pregnancy, and Meniere's disease.

Hormone therapy with ACTH and cortisone is used for several diseases. Sodium retention is one of the frequent metabolic consequences following administration of these therapeutic agents, and sodium-restricted diets are required, especially for long period of treatment, more recent medical text books continue to point out the usefulness of sodium-restricted diets for these several diseases where fluid retention is a problem (6).

When disease causes fluid retention in the body, with subsequent endema and ascites, there is a diminished urinary excretion of sodium and of water. If the sodium intake is restricted in these circumstances, further fluid retention will usually not occur, and the excess water ingested will be excreted in the urine because the mechanisms that maintain the concentration of sodium in the extracellular fluid do not permit the retention of water without sodium.

Almost all foods contain some sodium, and it is difficult to provide a nutritionally adequate diet without an intake of about 440 mg of sodium per day from food; this intake would be from the naturally occurring sodium in food with no salt added. The additional 60 mg that would increase the intake to the widely used restricted diet of 500 mg per day must account for all non-nutrition intake that occurs from drugs, water, and incidental intakes. A concentration of sodium in drinking water up to 20 mg per liter is considered compatible with this diet. When the sodium content exceeds 20 mg/l, the physician must take this into account to modify the diet or prescribe that distilled water be used. Water utilities that distribute water that exceeds 20 mg/l must inform physicians of the sodium content of the water so that the health of consumers can be protected. About 40 percent of the water supplies are known to exceed 20 mg/l and would be required to keep physicians informed of the sodium concentration (7). Most of the state health departments have made provision for determining the sodium content of drinking water on a routine basis and are now informing physicians in their jurisdiction (8). If change of source or a treatment change such as softening occurs that will significantly increase the sodium concentration, the utility must be sure that all physicians that care for consumers are aware of the impending change. Diets prescribing intakes of less than 500 mg per day must use special foods such as milk with the sodium reduced, or fruits that are naturally low in sodium.

It is not known how many persons are on sodium-restricted diets and to what extent the sodium intake is restricted. To reduce edema or swelling, the physician may prescribe a diuretic drug, a sodium-restricted diet, or a combination of the two. Therapy, of course, depends on the patient's condition, but there are also regional differences that probably result from physician training. The American Heart Association (AHA)(9) feels that diuretics may allow for less need of very restricted diets and that diuretics are necessary for quick results in acute conditions. For long-term use, a sodium-restricted diet is simpler, safer and more economical for the patient. It is preferable, especially when a moderate or mild sodium-restricted diet will effectively control the patient's hypertension and water retention. Literature is provided to physicians by the AHA to distribute to their patients explaining the sodium-restricted diets. These cover the "strict" restriction - 500 mg sodium, "moderate" restriction - 1000 mg sodium, and the "mild" restricted diet - 2400 to 4500 mg sodium. From 1958 through June 1971, there were 2,365,000 pieces of this literature distributed: 37% - 500 mg;

34% - 1000 mg; and 29% - "mild" (10). There are many ways a physician can counsel his patients other than using this literature, so the total distribution does not reflect the extent of the problem, but the proportion of booklets distributed may provide an estimate of the portion of diets that are prescribed. The "mild" restricted diet could require just cutting down on the use of salt, and literature for the patient would not be as necessary.

The AHA estimates that hypertension affects more than 21 million Americans, and in more than half of these cases put enough strain on the heart to be responsible for the development of hypertensive heart disease (11). Congestive heart failure is a sequelae of several forms of disease that damage the heart and would affect some unknown portion of the 27 million persons with cardiovascular disease. Thus, from 21 to 27 million Americans would be concerned with sodium intake.

Toxemias of pregnancy are common complications of gestation and occur in 6 to 7 percent of all pregnancies in the last trimester (12). Thus, about 230,000 women would be very concerned with sodium intake each year. Other diseases are treated with restricted sodium intake, but no estimate can be made on the number of people involved.

Questions about salt usage were asked on the ninth biennial examination of the National Heart Institute's Framingham, Massachusetts Study (13). The study population was free of coronary heart disease when the study began in 1949 and now are over 45 years of age. There were 3,833 respondents. Forty-five percent of the males and 30 percent of the females reported that they add salt routinely to their food before tasting. But at the other extreme, 9 percent of the men and 14 percent of the women avoid salt intake. More of the people 60 and over avoid salt intake than the 45 to 59 population. It is not determined if the salt restriction was medically prescribed nor how extensively the sodium intake was restricted.

It can be seen that a significant proportion of the population needs to and is trying to curtail its sodium intake. The sodium content of drinking water should not be significantly increased for frivolous reasons. This is particularly true of locations where many of the people using the water would be susceptible to adverse health effects, such as hospitals, nursing homes, and retirement communities. The use of sodium hypochlorite for disinfection, or sodium fluoride for control of tooth decay, would increase the sodium content of drinking water but to an insignificant amount. The use of sodium compounds for corrosion control might cause a significant increase, and softening by either the base exchange or lime-soda ash process would significantly increase the sodium content of drinking water. For each milligram per liter of hardness removed as calcium carbonate by the exchange process, the sodium content would be increased about one-half mg per liter. The increase in excess lime softening would depend on the amount of soda ash added. A study in North Carolina found that the sodium content of 30 private well-water supplies increased from 110 mg/l to 269 mg/l sodium on the average after softening (14). The sodium content of the softened water was much higher shortly after the softener had been regenerated than later in the cycle. A case has been reported where a replacement element type softener was not flushed, and the drinking water had a sodium content of 3,700 mg/l sodium when the unit was put back in service.

All consumers could use the water for drinking if the sodium content was kept below 20 mg per liter, but about 40 percent of the U.S. water supplies have a natural or added sodium content above this concentration (7). Many industrial wastes and runoff from deiced highways may increase the sodium pollution of surface water (15). The problem is most acute when groundwater is polluted with sodium (16, 17) because it remains for a long time. Removal of sodium from water requires processes being developed by the Office of Saline Water (18) and are economically feasible only in certain situations.

The person who is required to maintain a restricted sodium intake below 500 mg per day can use a water supply that contains 20 mg or less sodium per liter. If the water supply contains more sodium, low sodium bottled water or specially treated water will have to be used. In the moderately restricted diet that allows for a consumption of 1000 mg sodium per day the food intake is essentially the same, but the diet is liberalized to allow the use of 1/4 teaspoon of salt, some regular bakery bread, and/or some salted butter. If persons on the moderately restricted diet found it necessary to use a water with a significant sodium content they could still maintain their limited sodium intake with a water containing 270 mg/liter. This would require allocating all of the liberalized intake to water (the original 20 mg/l and 250 mg/l more with two liter domestic use, drinking or cooking, per day). High sodium in water causes some transfer of sodium to foods cooked in such water (5).

It is essential that the sodium content of public water supplies be known and this information be disseminated to physicians who have patients in the service area. Thus, diets for those who must restrict their sodium intake can be designed to allow for the sodium intake from the public water supply or the persons can be advised to use other sources of drinking water. Special efforts of public notification must be made for supplies that have very high sodium content so that persons on the more restricted sodium intake will not be overly stressed if they occasionally use these water supplies.

The 1963 Sodium Survey (7) had the following percent distribution of sodium concentration from 2100 public water supplies:

Range of Sodium Ion Concentration	Percent of Total Samples
mg/1	%
0-19.9	58.2
20-49.9	19.0
50-99.9	9.3
100-249.9	8.7
250-399.9	3.6
400-499.9	0.5
500-999.9	0.7
Over 1000	0.1

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APPENDIX C

Metric to English Equivalents

Conversion Factors

Length

Multiply	by	to obtain
cm	0. 3937	in.
m	3.281	ft.
m	1.094	yds.
km	0.6214	mi

Capacity

Multiply	by	to obtain
1 liter	0.0353	cu ft.
1 liter	0.2642	gals. (U.S.)
1 liter	61.025	cu in.

Area

Multiply	by	to obtain
sq. cm	0.1550	sq. in.
sq. m.	10.76	sq. ft.
sq. m.	1.196	sq. yd.
ha	2.471	acres
sq. km.	247.1	acres
sq. km.	0.3861	sq. mi.

Pressure

Multiply	by	to obtain
1 kg (force) per sq. cm.	14.2233	psi
1 kg per sq. m.	1.42×10^{-3}	psi
1 kg per sq. m.	0.20482	lb/sq. ft.
1 kg per sq. m.	3.281×10^{-3}	ft. of water
1 kg per cm.	0.96784	std. atm.
1 metric atm.	1.033228	kg per sq. cm.
1 std. atm.	14.6959	psi
1 N/m^3	0.00014	psi

Mass

Multiply	by	to obtain
gm	15.432	grains
gm	0.0353	oz.
gm	980.7	dynes
kg	2.205	lbs.
kg	0.0011	ton (short)
kg	10^{-3}	tons (metric)
tons (metric)	2205	lbs.

Volume

Multiply	by	to obtain
cu. cm.	0.061	cu. in.
cu. m.	35.31	cu. ft.
cu. m.	1.308	cu. yd.
cu. m.	264.2	gal. (U.S.)

Flow (Volumetric)

Multiply	by	to obtain
cu. m. /sec	15,850.0	gpm
l/sec.	15.850	gpm
cu. m. /sec	35.33	cfs

Density

Multiply	by	to obtain
gm/l	58.4	grains/gal.
gm/l	8.345	lb/1,000 gal.
gm/l	1000	(ppm) mg/l

Horsepower

Multiply	by	to obtain
hp (metric)	1.01387	hp (mech)

Horsepower * Formula

$$\text{bhp} = \frac{Q\ (\text{gpm}) \times H\ (\text{ft})}{3960 \times E} \times \text{sp gr}$$

$$\text{bhp} = \frac{Q\ (\text{m}^3/\text{hr}) \times H\ (\text{m})}{271\ 23 \times E} \times \text{sp gr}$$

* 1 hp = 33,000 ft. lb/min.

Temperature Formula

$$C^{o} = \frac{5}{9}\ (F - 32)$$

Power

Multiply	by	to obtain
watt*	0.056	B.T.U./min.
watt	0.7376	ft. lb/sec.
watt	$1.34 v 10^{-3}$	hp
watt	0.0143	kg cal/min.
kg-cal/min.	51.457	ft-lb/sec.
kg-cal/min.	0.0936	hp

* 1 watt = 1 J/S, 1 Joule = 1N-m, 1 kw = 1000 watts

Velocity (Linear)

Multiply	by	to obtain
m/sec.	3.28	fps
mm/sec.	0.00328	fps
km/sec.	2.230	mph
km/hr.	0.9113	fps

Viscosity

Multiply	by	to obtain
poise	1.45×10^{-5}	lb (weight) sec/sq. in.

ABBREVIATIONS

acre-foot	acre-ft
afternoon	PM
alternating-current (adj.)	a-c
ampere (s)	amp
ampere hour (s)	amp-hr
Angstrom units	Å
approximate, -ly	approx
aqueous	aq
atmosphere (s)	atm
atomic mass unit	a.m.u.
atomic weight	at wt
average	avg
avoirdupois	avdp
barrel (s)	bbl
Baume'	Be'
before noon	AM
billion electron volt (s)	Bev
billion gallons	bil gal
billion gallons per day	bgd
biochemical oxygen demand	BOD
board feet	fbm
(feet board measure)	fbm
brake horsepower	bhp
British thermal unit (s)	Btu
bushel (s)	bu
calorie (s)	cal
capita	cap
centigrade	C°
centigram (s)	cg
centiliter (s)	cl
centimeter (s)	cm
chemical oxygen demand	COD
chemically pure	cp
concentrated	con
concentration	concn
counts per minute	cpm
counts per second	cps
cubic	cu
cubic centimeter (s)	cu cm = ml
cubic feet per day	cfd
cubic feet per hour	cfh
cubic feet per minute	cfm
cubic feet per second	cfs
cubic foot (feet)	cu ft.
cubic inch (es)	cu in.
cubic meter (s)	cu m
cubic micron (s)	cu
cubic millimeter (s)	cu mm
cubic yard (s)	cy yd
curie (s)	Ci
current density	cd
cycles per second	Hz
decibels	db
deciliter (s)	dl
decimeter (s)	dm
degree (s)	deg
degree (s) Centigrade (Celsius).	°C
degree (s) Fahrenheit	°F
diameter	diam
dilute (adj.)	dil
direct-current (adj.)	d-c
disintegrations per minute	dpm
dissolved oxygen	DO
dissolved solids	DS
dram (s)	dr
efficiency	E
electromotive force	emf
electron volt	ev
elevation	el
equation	eq
ethylenediaminetetraacetate	EDTA
exponential	exp
fahrenheit°	F°
feet	ft
feet board measure (board feet).	fbm
feet per day	fpd
feet per hour	fph
feet per minute	fpm
feet per second	fps
figure (s)	Fig
foot	ft
foot-candle (s)	ft-c
foot-pound (s)	ft-lb
free on board	fob

gallons (s)	gal
gallons (s) (Imperial)	gal (Imp)
gallons (s) per capita per day	gpcd
gallon (s) per day	gpd
gallon per day per acre	gpd/acre
gallons per day per capita	gpd/cap
gallons per day per square foot	gpd/sq ft
gallon (s) per hour	gph
gallon (s) per minute	gpm
gallon (s) per minute per square foot	gpm/sq ft
gallon (s) per second	gps
grain (s) per gallon	g/g
gram (s)	g
grams per liter	g/l
gram-molecule	mole
head	H
hectare (s)	ha
height	h
hertz	Hz
horsepower	hp
horsepower-hour (s)	hp-hr
hour (s)	hr
hundredweight	cwt
hydrogen ion concentration (-log H^+)	pH
immediate oxygen demand	IOD
inch (es)	in.
inch (es) per second	ips
inch (es) per minute	ipm
inch-pound (s)	in.-lb
indicated horsepower	ihp
infra-red	ir
inside diameter	id
insoluble	insol
international unit	i.u.
ionic strength	I
Jackson turbidity units	Jtu

Kelvin°	K°
kilocalorie (s)	kcal
kilocurie	K Ci
kilocycle (s)	kc
kilogram (s)	kg
kiloliter (s)	kl
kilometer (s)	km
kilovolt (s)	kv
kilovolt-ampere (s)	kva
kilowatt (s)	kw
kilowatt-hour (s)	kwh
linear foot	lin ft
liters	l
logarithm (common-base 10)	log
logarithm (natural-base e)	ln
man-hour (s)	man-hr
maximum	max
maximum permissible concentration	MPC
maximum permissible level	MPL
mean sea level	MSL
median tolerance limit	TL_m
membrane filter	MF
meter (s)	m
mho (s)	mho
microampere (s)	μa
microcurie (s)	μCi
microgram (s)	μg
microgram (s) per liter	μg/l
microinch (es)	μin.
microliter	μl
micrometer (s)	μm
micromho (s)	μmho
micromicrocurie (s)	μμCi
micromicron (s)	μμ
micromole	μ mole
micron (s)	μ
microvolt (s)	μv
microwatt (s)	μw
mile (s)	mi
mile (s) per hour	mph

milliampere (s)	ma
millicurie (s)	mCi
milliequivalent (s)	meq
milligram (s)	mg
milligrams per liter	mg/l
Millihert	mHz
milliliter (s)	ml
millimeter (s)	mm
millimicrogram (s)	mμg
millimicron (s)	mμ
millimolar	mM
million electron volt	Mev
million gallons	mil gal
million gallons per day	mgd
million gallons per day per acre	mgd/acre
milliroentgens	mr
millivolt (s)	mv
minimum	min.
minute (s)	min
mixed liquor suspended solids	MLSS
molar (concentration)	M
mole	mole
molecular weight	mol wt
molecul-e, -ar	mol
most probable number	MPN
nanocurie (s) (10^{-9} curie)	nCi
neutron	n
normal (concentration)	N
number (s)	No.
newton	N
otho-tolidine	OT
otho-tolidine-arsenite	OTA
ounce (s)	oz
ounce-foot (feet)	oz-ft
ounce-inch (es)	oz-in.
outside diameter	od
oxidation-reduction potential	ORP
oxygen consumed	OC
part (s) per billion	ppb = g/l
part (s) per million	ppm[*] = mg/l[**]
part (s) per thousand	ppt
percent	percent
percent (vol in vol)	percent(v/v)
percent (wt in vol)	percent(w/v)
percent (wt in wt)	percent(w/w)
picocurie (s) (10^{-12} curie)	pCi
potential difference	p.d.
pound (s)	lb
pound-mole	lb-mole
pound (s) per acre	lb/acre
pound (s) per acre-foot	lb/acre-ft.
pound (s) per day per acre	lb/day/acre
pound (s) per day per cubic foot	lb/day/cu ft
pound (s) per square foot	psf
pound (s) per square foot per hour	psf/hr
pound (s) per square inch	psi
pound (s) per square inch absolute	psia
pound (s) per square inch gage	psig
pound (s) per thousand cubic feet	lb/1,000 cu ft
precipitate (as a noun)	ppt
precipitated	pptd
precipitating	pptg
precipitation	pptn
quart (s)	qt
radiation absorbed dose	rad
reciprocal ohm (s)	mho
resistance (ohms)	R
revolution (s) per minute	rpm
revolution (s) per second	rps
roentgen (s)	r
roentgen equivalent (s) man	rem
saturated calomel electrode	S.C.E.
second (s)	sec
second feet (cubic feet per second)	cfs
second feet days	sfd

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[*] For gases

[**] For aqueous solutions; for non-aqueous solutions, correct for density.

side water depth	SWD
sludge density index	SDI
sludge volume index	SVI
soluble	sol
solution	soln
specific gravity	sp gr
specific heat	sp ht
square	sq
square centimeter (s)	sq cn
square foot (feet)	sq ft
square inch (es)	sq in.
square kilometer (s)	sq km
square meter (s)	sq m
square micron (s)	sq
square mile (s)	sq mi
square millimeter (s)	sq mm
square yard (s)	sq yd
suspended solids	SS
switch	sw
time	t
tons per day	tpd
total oxygen demand	TOD
total solids	TS
total suspended solids	TSS
total volatile solids	TVS
ultra-violet	uv
unit of pressure (mm Hg)	torr
United States Pharmacopoeia	USP
volatile solids	VS
volatile suspended solids	VSS
volt (s)	v
volt-ampere (s)	va
volume	vol
watt (s)	w
watt-hour (s)	whr
week (s)	wk
weight	wt
yard (s)	yd
year (s)	yr

APPLICATION OF UNITS

Description	Unit	Symbol	English Equivalents
Air supply	cubic meter or liter of free air per second	cu m/s l/s	0.02832 cu ft/s 28.32 cu ft/s
BOD loading	kilogram per cubic meter per day	kg/ cu m day	0.0624 lb/cu ft day
Concentration	milligram per liter	mg/l	1 ppm
Density	kilogram per cubic meter	kg/cu m	0.0624 lb/cu ft
Discharge or abstractions, yields	cubic meter per day	cu m/day	1.83 x 10^{-1} gpm
Flow in pipes, conduits, channels, over weirs, pumping	cubic meter per second liter per second	cu m/sec l/s	0.2272 gpm 15.85 gpm
Hydraulic load per unit area; e.g. filtration, rates	cubic meter per square meter per day	cu m/sq m day	3.28 cu ft/sq ft day
Hydraulic load per unit volume, e.g. biological filters, lagoons	cubic meter per cubic meter per day	cu m/cu m day	cu ft/cu ft day
Optical units	lumen per square meter	lumen/sq m	0.092 ft candle/sq ft
Pipes-diameter length	millimeter meter	mm m	0.03937 in 3.28 ft
Precipitation, run-off evaporation	millimeter	mm	0.03937 in
Water usage	liter per person per day	l/person day	0.264 gcpd

APPENDIX D

ADMINISTRATOR'S DECISION STATEMENT NO. 5

Dated Feb. 6, 1973

SUBJECT: EPA POLICY ON SUBSURFACE EMPLACEMENT OF FLUIDS BY WELL INJECTION

This ADS records the EPA's position on injection wells and subsurface emplacement of fluids by well injection, and supersedes the Federal Water Quality Administration's order COM 5040.10 of October 15, 1970.

GOALS

The EPA Policy on Subsurface Emplacement of Fluids by Well Injection is designed to:

1. Protect the subsurface from pollution or other environmental hazards attributable to improper injection or ill-sited injection wells.
2. Ensure that engineering and geological safeguards adequate to protect the integrity of the subsurface environment are adhered to in the preliminary investigation, design, construction, operation, monitoring and abandonment phases of injection well projects.
3. Encourage development of alternative means of disposal which afford greater environmental protection.

PRINCIPAL FINDINGS AND POLICY RATIONALE

The available evidence concerning injection wells and subsurface emplacement of fluids indicates that:

1. The emplacement of fluids by subsurface injection often is considered by government and private agencies as an attractive mechanism for final disposal or storage owing to: (1) the diminishing capabilities of surface waters to receive effluents without violation of quality standards, and (2) the apparent lower costs of this method of disposal or storage over conventional and advanced waste management techniques. Subsurface storage capacity is a natural resource of considerable value and like any other natural resource its use must be conserved for maximal benefits to all people.

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2. Improper injection of municipal or industrial wastes or injection of other fluids for storage or disposal to the subsurface environment could result in serious pollution of water supplies or other environmental hazards.

3. The effects of subsurface injection and the fate of injected materials are uncertain with today's knowledge and could result in serious pollution or environmental damage requiring complex and costly solutions on a long-term basis.

POLICY AND PROGRAM GUIDANCE

To ensure accomplishment of the subsurface protection goals established above it is the policy of the Environmental Protection Agency that:

1. The EPA will oppose emplacement of materials by subsurface injection without strict controls and a clear demonstration that such emplacement will not interfere with present or potential use of the subsurface environment, contaminate ground water resources or otherwise damage the environment.

2. All proposals for subsurface injection should be critically evaluated to determine that:

   (a) All reasonable alternative measures have been explored and found less satisfactory in terms of environmental protection;

   (b) Adequate preinjection tests have been made for predicting the fate of materials injected;

   (c) There is conclusive technical evidence to demonstrate that such injection will not interfere with present or potential use of water resources nor result in other environmental hazards;

   (d) The subsurface injection system has been designed and constructed to provide maximal environmental protection.

   (e) Provisions have been made for monitoring both the injection operation and the resulting effects on the environment;

(f) Contingency plans that will obviate any environmental degradation have been prepared to cope with all well shut-ins or any well failures;

(g) Provision will be made for plugging injection wells when abandoned and for monitoring plugs to ensure their adequacy in providing continuous environmental protection.

3. Where subsurface injection is practiced for waste disposal, it will be recognized as a temporary means of disposal until new technology becomes available enabling more assured environmental protection.

4. Where subsurface injection is practiced for underground storage or for recycling of natural fluids, it will be recognized that such practice will cease or be modified when a hazard to natural resources or the environment appears imminent.

5. The EPA will apply this policy to the extent of its authorities in conducting all program activities, including regulatory activities, research and development, technical assistance to the States, and the administration of the construction grants, State program grants, and basin planning grants programs and control of pollution at Federal facilities in accordance with Executive Order 11507.

1 Accession Number	2 Subject Field & Group	**SELECTED WATER RESOURCES ABSTRACTS** INPUT TRANSACTION FORM

5 *Organization*

Environmental Planning and Engineering
a division of
David Volkert & Associates, Bethesda, Maryland.

6 *Title*

Monograph on the Effectiveness and Cost of Water Treatment Processes for the Removal of Specific Contaminants.

10 *Author(s)*

Ian C. Watson
Stephen J. Spano
Howard N. Davis
Frederick M. Heider

16 *Project Designation*

EPA, WQO Contract No. 68-01-1833

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

*Water Treatment Methods and Processes, *Water Treatment Costs, Treatment Process Selection, Water Source Protection, Treated Water Storage, Control of Water Quality in Distribution System.

25 *Identifiers (Starred First)*

*Effectiveness and Cost of Water Treatment

27 *Abstract*

This monograph provides information on treatment processes for potable water supplies and their costs. It is intended as a general planning document, giving the user general concepts on what treatment methods are available to remove specific contaminants or reduce them below the limits required or recommended by the 1974 Federal Drinking Water Standards and Guidelines. These contaminants may be physical, biological, radiological, or chemical. General cost estimates for the removal or reduction of contaminant levels can be made by using the cost estimation curves and procedures outlined in the monograph. Volume II of the monograph is a KWIK INDEX which provides additional references for more detailed information on treatments and costs.

This report was submitted in fulfillment of EPA contract 68-01-1833 under the sponsorship of the Water Quality Office, Environmental Protection Agency.

Abstractor Frederick M. Heider	*Institution* Environmental Planning and Engineering

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